IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF TEXAS
DALLAS DIVISION

VERTIV CORPORATION, Plaintiff, v. VALTRUS INNOVATIONS LIMITED, Defendant.	Civil Action No. 3:24-cv-1152 **JURY TRIAL DEMANDED**

COMPLAINT FOR DECLARATORY JUDGMENT

Plaintiff, Vertiv Corporation, ("Vertiv"), for its Original Complaint against Defendant, Valtrus Innovations Limited ("Valtrus"), alleges as follows:

NATURE OF THE ACTION

1. This is an action for a declaratory judgment of non-infringement of United States Patent Nos. 6,718,277 ("the '277 Patent"), 6,854,287 ("the '287 Patent"); 6,862,179 ("the '179 Patent"); 7,031,870 ("the '870 Patent"); and 7,339,490 ("the '490 Patent") (collectively, "the Patents-in-Suit") arising under the Declaratory Judgment Act, 28 U.S.C. §§ 2201 and 2202, and the patent laws of the United States, including Title 35, United States Code.

2. This action arises from Valtrus' ongoing campaign to interfere with Vertiv's relationship with its valued customers by aggressively and serially pursuing unfounded and false claims of patent infringement of the Patents-in-Suit in letters and by filing lawsuits based on the customers' use of Vertiv data center cooling, control and sensor products.

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3. Vertiv's products cannot infringe the Patents-in-Suit because the products do not practice the Patents-in-Suit asserted by Valtrus against its customers. The infringement assertions against Vertiv's customers are therefore baseless and unjustified.

4. Vertiv seeks relief resolving the controversy between the real parties in interest, Valtrus and Vertiv, to protect its relationships with its many customers and to remove the uncertainty and false accusations of patent infringement against its products.

PARTIES AND BACKGROUND

5. Vertiv is an American multi-national publicly traded corporation that is incorporated in Delaware and has its principal place of business at 505 N. Cleveland Ave., Westerville, OH 43082 in Franklin County. Vertiv is a provider of critical infrastructure and services for data centers and related facilities.

6. Intellectual property is important to Vertiv. Vertiv continually invests in research and development and has received hundreds of U.S. patents and thousands of patents globally for its innovations.

7. Vertiv also values its relationships with its customers. Part of Vertiv's success is standing behind its products and services. One way that Vertiv stands by its products is through indemnity agreements.

8. Upon information and belief, Valtrus is an Irish entity duly organized and existing under the laws of the Republic of Ireland. The address of the registered office of Valtrus is: The Glasshouses GH2, 92 Georges Street Lower, Dun Laoghaire, Dublin A96 VR66, Ireland.

9. Upon information and belief, Valtrus does not have any employees who live or work within the United States of America.

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10. There are direct flights from Dublin, Ireland to Dallas-Fort Worth International Airport.

11. On information and belief, Valtrus' business purpose is as "the owner of an extensive portfolio of patents originating from Hewlett Packard Enterprise Company [HPE]. Valtrus' portfolio covers a range of products and technologies including servers, cloud and data centre management, memory, processors, WLAN, network analytics, power and many more related technologies. The portfolio includes patents whose use are ubiquitous in these areas. Valtrus is focused on licensing these patents to established players and new entrants in the applicable market." *See* www.valtrusinnovations.ie.

12. Upon information and belief, Valtrus does not make, use, or offer for sale any products in the United States.

13. Upon information and belief, Valtrus' activities in the United States relate only to the enforcement and licensing of its patent portfolio.

14. Upon information and belief, none of the named inventors on the Patents-in-Suit is currently or ever has been a Valtrus employee.

15. As part of its patent enforcement efforts, Valtrus sued Google LLC for patent infringement in the Northern District of Texas in the case *Valtrus Innovations Ltd. v. Google LLC*, 3:22-cv-00066, which is currently pending.

16. In 2023 and 2024, Valtrus also sued:

- SAP America, Inc. et al, 2:24-cv-00021;
- AT&T Inc. et al, 2:23-cv-00443;
- T-Mobile USA, Inc. et al, 2:23-cv-00444; and
- Verizon Communications Inc. et al, 2:23-cv-00445,

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all in the Eastern District of Texas and on patents that are not the Patents-in-Suit in this controversy.

17. In 2024, Valtrus filed lawsuits against Vertiv's direct customers alleging patent infringement of the Patents-in-Suit against:

- Digital Realty Trust, Inc. and Digital Realty Trust, L.P. (collectively, "Digital Realty"), 2:24-cv-00139-JRG;
- Dawn Acquisitions LLC (d/b/a Evoque Data Center Solutions), 2:24-cv-00142-JRG;
- CyrusOne, LLC, 2:24-cv-00259-JRG; and
- NTT Data Services, LLC et al., 2:24-cv-00361-JRG

all in the Eastern District of Texas and based on their use of Vertiv products.

18. Valtrus' infringement claim charts for the Patents-in-Suit refer extensively to technical product information from brochures, user manuals, and web sites for Vertiv products. *See* e.g., Exhibit F (Complaint against CyrusOne in the Eastern District of Texas with claim charts for the Patents-in-Suit based on its use of Vertiv products).

19. As the purported support for its infringement assertions involving Vertiv products, Valtrus relies on features and methodologies provided and executed by Vertiv products in their normal modes of operation, as reflected in the Vertiv product information cited throughout Valtrus' claim charts. For example, one of Valtrus' allegations is that CyrusOne infringes because it uses "Vertiv and Liebert cooling in its U.S. data centers to control atmospheric conditions. Liebert's cooling units are controlled, for example, by Liebert's iCOM and/or iCOM-S Intelligent Communication and Monitoring system…" Exhibit F (Valtrus Complaint against CyrusOne, Exhibit 8, page 6).

20. Liebert is a brand name for some Vertiv products.

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21. In 2024, Valtrus's litigation counsel, Matthew Berkowitz, sent letters on behalf of Valtrus to at least ten data center corporations accusing those companies of infringing one or more of the Patents-In-Suit based on their use of Vertiv products and enclosing substantially the same claim charts for the Patents-In-Suit as in the currently pending lawsuits involving those patents in the Eastern District of Texas.

22. The claim charts attached to Mr. Berkowitz's letters allege infringement of the Patents-in-Suit based on the use of Vertiv's products and the features and operations of those products described in Vertiv's product literature. The letters implicitly threaten litigation by referencing the case numbers for the litigation Valtrus initiated against Digital Realty and Evoque, setting a deadline for the recipient to agree to meet to discuss a license, and stating that Valtrus "reserves all rights" should the recipient decline such a meeting.

23. At least three of those letters were sent to addresses in Dallas, TX within this District. For example, Mr. Berkowitz sent a patent infringement notice letter to CyrusOne's General Counsel at its place of business in Dallas, TX on behalf of Valtrus dated March 29, 2024, alleging infringement of and offering a license to the Patents-in-Suit. *See* Exhibit G.

24. Upon information and belief, Valtrus' patent infringement notice letters also copied its licensing agent, Patent Platform Services LLC on the letters. PPS has a principal place of business located at 7460 Warren Parkway, Suite 100, Frisco, Texas 75034, and has several employees who reside and work in Texas including in relation to services provided on behalf of Valtrus.

25. On information and belief, several of the customers to whom Valtrus sent patent infringement notice letters own or operate data centers within the Northern District of Texas.

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26. On information and belief, some of the customers to whom Valtrus sent patent infringement notice letters do not own or operate any data centers within the Eastern District of Texas.

27. On information and belief, at least one of the customers to whom Valtrus sent a patent infringement notice letter does not own or operate any data centers within Texas.

28. On information and belief, Mr. Berkowitz and/or other representatives of Valtrus have initiated other correspondence and communications with Vertiv's customers, including customers having a presence in Texas, in furtherance of Valtrus's attempts to pressure those customers into purchasing a license to Valtrus' patents.

29. On information and belief, Valtrus will continue sending patent infringement notice letters to additional Vertiv customers based on their use of Vertiv products in their data centers.

30. On information and belief, Valtrus and/or one or more of the named defendants intend to seek discovery from Vertiv about the Vertiv products that Valtrus alleges are infringing in the Eastern District of Texas cases against Digital Realty, Evoque, CyrusOne, and NTT Data Systems.

31. On information and belief, Valtrus would also seek to procure discovery from Vertiv about its products if it were to file additional lawsuits against any Vertiv customers based on the allegations in the many patent infringement notice letters it has already sent or is planning to send.

32. Each additional customer lawsuit that Valtrus files will continue to increase the cost to Vertiv of complying with discovery requests and will disrupt Vertiv's business priorities as a provider of critical infrastructure and services for data centers and related facilities.

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33. As part of highly valuing its customer relationships, Vertiv has notified customers that have been sued that it will indemnify them from Valtrus' patent infringement allegations related to the use of Vertiv products and services.

34. Vertiv desires to clear its name and its products of the allegations of patent infringement made by Valtrus against its customers and to alleviate the strain imposed on its customer relationships by these false accusations.

JURISDICTION

35. This action arises under the Declaratory Judgment Act, 28 U.S.C. §§ 2201 and 2202, and the patent laws of the United States, 35 U.S.C. § 1 et seq.

36. This court has original jurisdiction over the subject matter of this action pursuant to 28 U.S.C. §§ 1331, 1132, 1338(a), and/or 1367, 2201, and 2202.

37. The amount in controversy exceeds $75,000. All the allegations contained herein form part of the same case or controversy.

38. Upon information and belief, Valtrus owns all rights, title, and interest in the Patents-in-Suit.

39. Upon information and belief, Valtrus possess all rights of recovery for allegations of infringement of the Patents-in-Suit.

40. Personal jurisdiction over Valtrus is proper because Valtrus has purposefully directed activities or transactions to this forum and has performed acts purposefully availing itself of the privilege of conducting activities in this forum related to the subject matter of this case. Specifically, Valtrus acquired the patents that it owns from Hewlett Packard Enterprise Development, LP, and Hewlett Packard Enterprise Company, the former being a Texas limited partnership having its principal place of business in Houston, Texas. After acquiring ownership of

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the patents, Valtrus sent letters to companies within this forum asserting allegations of patent infringement and offering a license to the Patents-in-Suit and/or seeking a meeting regarding licensing of the Patents-in-Suit. Valtrus chose a Texas-based licensing agent, PPS, to support and participate in its efforts to extract licensing revenue from Vertiv customers based on their use of Vertiv products. A substantial part of the events giving rise to the dispute occurred in this district, including when Valtrus contacted and threatened Vertiv's Dallas-based customers as well as customers who operate data centers located in this District.

41. Personal jurisdiction is also proper because Valtrus has filed suit for patent infringement against Google in this District and consented to this Court's jurisdiction and convenience as a forum as part of its patent enforcement strategy.

42. Valtrus has acknowledged that its purposeful activities subject it to the personal jurisdiction of Courts in the State of Texas. In particular Valtrus submitted a Declaration of its Managing Director, Angela Quinlan, in connection with the action *SAP America, Inc. v. Valtrus Innovations Ltd. et al*, 24-cv-54-GBW (D. Del. Jan. 15, 2024). *See* Exhibit H. The Quinlan Declaration acknowledges, inter alia, the numerous patent infringement lawsuits Valtrus has filed and is pursuing in the federal courts in Texas and the fact all of Valtrus' patents were acquired from Hewlett Packard Enterprises, which is based in Texas. *See id.* at ¶¶ 6, 12. Valtrus, via the Quinlan Declaration, further acknowledged, agreed and consented that jurisdiction over Valtrus is proper in Texas. *See id*. at ¶ 13.

43. Valtrus has availed itself of the rights and benefits of the laws of Texas. It has conducted business relating to the licensing and enforcement of its patents in Texas, directly and through Patent Platform Services and/or other agents, and it has systematic and continuous business contacts with Texas through its patent enforcement and licensing activities.

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44. To the extent that Valtrus lacks sufficient contacts with any state, Vertiv alleges in the alternative that personal jurisdiction over Valtrus is also proper under Fed. R. Civ. Pro. 4(k)(2) in this District because this case relates to Valtrus' assertions of patent infringement and therefore arises under federal law; Valtrus is an Irish corporation; and Valtrus has sufficient contacts with the United States as a whole, as it is directing its patent enforcement efforts toward various United States entities. For example, Valtrus has pursued judicial patent enforcement in this forum by filing suit in at least *Valtrus Innovations Ltd. v. Google LLC*, 3:22-cv-00066 (N.D. Tex. Jan. 10, 2022); *Valtrus Innovations Ltd. v. SAP America, Inc. et al*, 2:24-cv-00021-JRG (E.D. Tex. Jan. 15, 2024); *Valtrus Innovations Ltd. v. AT&T Inc. et al*, 2:23-cv-00443-JRG (E.D. Tex. Sept. 27, 2023); *Valtrus Innovations Ltd. v. Digital Realty Trust, Inc. et al*, 2:24-cv-00139-JRG (E.D. Texas Feb. 27, 2024); *Valtrus Innovations Ltd. v. Dawn Acquisitions LLC (d/b/a Evoque Data Center Solutions)*, 2:24-cv-00142-JRG (E.D. Tex. Feb. 27, 2024); *Valtrus Innovations Ltd. v. T-Mobile USA, Inc. et al*, 2:23-cv-0444-JRG (E.D. Tex. Sept.27, 2023); *Valtrus Innovations Ltd. v. Verizon Communications Inc. et al*, 2:23-cv-0445-JRG (E.D. Tex. Dec. 4, 2023); *Valtrus Innovations Ltd. v. CyrusOne, LLC*, 2:24-cv-00259-JRG (E.D. Tex. April 17, 2024); and *Valtrus Innovations Ltd. v. NTT Data Services, LLC et al*., 2:24-cv-00361-JRG (E.D. Tex. May 14, 2024).

VENUE

45. Venue is proper in this district under 28 U.S.C. § 1391 because a substantial part of the events giving rise to the dispute occurred in this District and because Valtrus is subject to personal jurisdiction in this District. Venue is also proper because Valtrus is a foreign Company and may be sued in any judicial district in the United States in which Valtrus is subject to the Court's personal jurisdiction. Valtrus' choice of this District for its currently pending patent

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litigation against Google and the presence of an international airport with direct flights from Valtrus' home city shows that this is also a convenient forum for Valtrus.

FACTS

THE PATENTS AT ISSUE

46. The '277 Patent entitled "Atmospheric Control Within a Building," names Ratnesh Sharma as the inventor and states an issue date of April 6, 2004. Attached as Exhibit A is a true and correct copy of the '277 Patent.

47. The '277 Patent is directed to a method and system for controlling atmospheric conditions within a building.

48. On information and belief, Valtrus is the assignee of all right, title, and interest in the '277 Patent.

49. The '277 Patent has expired.

50. The '287 Patent entitled "Cooling System," names Chandrakant D. Patel and Cullen E. Bash as the inventors and states an issue date of February 15, 2005. Attached as Exhibit B is a true and correct copy of the '287 Patent.

51. The '287 Patent is directed to a system, method, and computer readable storage medium for cooling a room configured to house a plurality of computer systems.

52. On information and belief, Valtrus is the assignee of all right, title, and interest in the '287 Patent.

53. The '287 Patent has expired.

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54. The ‘179 Patent entitled “Partition for Varying the Supply of Cooling Fluid,” names Abdlmonem H. Beitelmal and Chandrakant D. Patel as the inventors and states an issue date of March 1, 2005. Attached as Exhibit C is a true and correct copy of the ‘179 Patent.

55. The ‘179 Patent is directed to a method, system, and apparatus for cooling a plurality of racks in a data center.

56. On information and belief, Valtrus is the assignee of all right, title, and interest in the ‘179 Patent.

57. The ‘179 Patent has expired.

58. The ‘870 Patent entitled “Data Center Evaluation Using Air Re-Circulation Index,” names Ratnesh K. Sharma, Cullen E. Bash, and Chandrakant D. Patel as the inventors and states an issue date of April 18, 2006. Attached as Exhibit D is a true and correct copy of the ‘870 Patent.

59. The ‘870 Patent is directed to a system, method, computational fluid dynamics tool, and a computer readable storage medium for evaluating one or more components in a data center.

60. On information and belief, Valtrus is the assignee of all right, title, and interest in the ‘870 Patent.

61. The ‘490 Patent entitled “Modular Sensor Assembly,” names David Allen Moore, Rober Allen Pereira, Ratnesh K. Sharma, and Cullen E. Bash as the inventors and states an issue date of March 4, 2008. Attached as Exhibit E is a true and correct copy of the ‘490 Patent.

62. The ‘490 Patent is directed to a modular system assembly for sensing a condition at a computer rack, a sensor system, and a computer rack system.

63. On information and belief, Valtrus is the assignee of all right, title, and interest in the ‘490 Patent.

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EXISTENCE OF AN ACTUAL CONTROVERSY

64. There is an actual controversy within the jurisdiction of this Court under 28 U.S.C. §§ 2201 and 2202.

65. On information and belief, Valtrus has provided at least ten of Vertiv's customers with patent infringement notice letters and claim charts purporting to show how the use of Vertiv's products infringes at least one claim of each of the Patents-in-Suit. The claim charts also implicitly contain allegations of direct and indirect infringement (jointly and contributorily) against Vertiv.

66. Valtrus has also filed four patent infringement suits based on allegations that using Vertiv products infringes at least one claim of each of the Patents-in-Suit. The claim charts in each of those cases also implicitly contain allegations of direct and indirect infringement (jointly and contributorily) against Vertiv.

67. Vertiv values its customer relationships and is contractually bound to indemnify and defend customers against patent infringement claims related to the use of Vertiv products pursuant to various contracts and sales agreements.

68. On information and belief, Valtrus has also filed at least eight patent infringement lawsuits in 2023 and 2024, making clear that filing lawsuits is a major strategy of its only U.S. business, the enforcement of its patents.

69. Valtrus' assertions of patent infringement against Vertiv's customers and products have created uncertainty in Vertiv's relationships with its many customers and harmed its reputation in its industry. Vertiv understandably desires to clear this cloud of controversy and maintain its reputation.

70. It is not in the substantial interest of justice or an efficient use of judicial resources for Vertiv to be forced to defend itself and its customers from Valtrus' unjustified patent

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infringement claims serially and concurrently in suits against each customer individually in various forums of Valtrus' choice.

71. Based on the foregoing, a justiciable controversy exists between Vertiv and Valtrus as to whether Valtrus' products, such as the Leibert cooling and iCOM control products and modular sensors, and services infringe the Patents-in-Suit.

72. Absent a declaration of non-infringement for Vertiv's products that applies to all of its customers, Valtrus will continue to wrongfully allege that Vertiv's products and services infringe the Patents-in-Suit, will continue to contact and sue customers in repetitive cases in various forums increasing the cost of defense to Vertiv and its customers, and will, thereby, cause Vertiv irreparable injury and damage.

COUNT I
(Declaratory Judgment of Non-Infringement of the '277 Patent)

73. Vertiv repeats and realleges paragraphs 1 through 72 hereof, as if fully set forth herein.

74. Valtrus has asserted that it is the owner of the '277 Patent.

75. Valtrus has alleged that products of Vertiv, including Liebert cooling units and Liebert iCOM and iCOM-S control systems, infringe the '277 Patent.

76. As a result of the acts described in the preceding paragraphs, there exists a controversy of sufficient immediacy and reality regarding whether Vertiv's products infringe any claims of the '277 Patent to warrant the issuance of a declaratory judgment of non-infringement.

77. A judicial declaration is necessary and appropriate so that Vertiv may ascertain its rights regarding its Liebert cooling and iCOM products and the '277 Patent.

78. Vertiv products (including Liebert cooling units and Liebert iCOM and iCOM-S control systems) do not infringe the '277 Patent and Vertiv has not contributed to or induced

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infringement of the '277 Patent because Vertiv products do not practice or embody the limitations of the claims of the '277 Patent. By way of example, neither Vertiv nor its Liebert cooling units and/or Liebert iCOM and iCOM-S control system products has infringed or infringes the '277 Patent at least because the products do not practice a method of controlling atmospheric conditions within a building upon sensing atmospheric parameters at locations inside the building involving the steps of "generating an empirical atmospheric map from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical atmospheric map"; "comparing said empirical atmospheric map to a template atmospheric map"; and "identifying pattern differential between said empirical and template atmospheric maps" as required by independent claim 1 of the '277 Patent.

79. As another example, independent claim 12 is directed to a method of cooling a data center involving supplying cooling fluid to cool equipment within the data center and sensing temperature at locations within the data center. The method of claim 12 further requires "generating an empirical thermal map of said data center from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical thermal map"; "comparing said empirical thermal map to a template thermal map"; and "identifying pattern differentials between said empirical and template thermal maps." Vertiv's products, including its Liebert cooling units and Liebert iCOM and iCOM-S control system products, do not practice these steps of claim 12 of the '277 Patent.

80. As another example, independent claim 22 is directed to a system for controlling atmospheric conditions within a building that includes means for sensing at least one atmospheric parameter at locations inside the building. The system of claim 22 further requires "means for generating an empirical atmospheric map from said means for sensing, wherein the means for

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generating comprises software for processing input from said means for sensing and for producing output in the form of said empirical atmospheric map"; "means for comparing said empirical atmospheric map to a template atmospheric map"; and "means for identifying characteristics of pattern differentials between said empirical and template atmospheric maps." Vertiv's products, including its Liebert cooling units and Liebert iCOM and iCOM-S control system products, do not meet these limitations of claim 22 of the '277 Patent.

81. For at least these reasons, Vertiv's products, including its Liebert cooling units and Liebert iCOM and iCOM-S control systems, do not infringe the '277 Patent.

82. Vertiv is entitled to a declaratory judgment that its products, including its Liebert cooling units and Liebert iCOM and iCOM-S control systems, have not infringed and do not infringe, either directly or indirectly, literally under the doctrine of equivalents, any claim of the '277 Patent.

COUNT II
(Declaratory Judgment of Non-Infringement of the '287 Patent)

83. Vertiv repeats and realleges paragraphs 1 through 72 hereof, as if fully set forth herein.

84. Valtrus has asserted that it is the owner of the '287 Patent.

85. Valtrus has alleged that products of Vertiv, including Liebert cooling units (both refrigerant-based and chilled water systems), and Liebert iCOM control systems, infringe the '287 Patent.

86. As a result of the acts described in the preceding paragraphs, there exists a controversy of sufficient immediacy and reality regarding whether Vertiv's products infringe any claims of the '287 Patent to warrant the issuance of a declaratory judgment of non-infringement.

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87. A judicial declaration is necessary and appropriate so that Vertiv may ascertain its rights regarding its Liebert cooling and iCOM products and the '287 Patent.

88. Vertiv products (including Liebert cooling units and Liebert iCOM control systems) do not infringe the '287 Patent and Vertiv has not contributed to or induced infringement of the '287 Patent because Vertiv products do not practice or embody the limitations of the claims of the '287 Patent. By way of example, neither Vertiv nor its Liebert cooling units and/or Liebert iCOM control system products has infringed or infringes the '287 Patent at least because the products do not practice a method of cooling a room housing computer systems involving the steps of "supplying [a] plurality of heat exchanger units with cooling fluid from an air conditioning unit"; "cooling . . . received air through heat exchange with the cooling fluid in the plurality of heat exchanger units"; "controlling at least one of the temperature of said cooling fluid and said air delivery by said plurality of heat exchanger units to said room in response to said sensed temperatures at said one or more locations"; and "controlling . . . air delivery by said plurality of heat exchanger units [by] individually manipulating a mass flow rate of the cooling fluid supplied to each of the plurality of heat exchanger units" as required by independent claim 1 of the '287 Patent.

89. As another example, independent claim 10 recites a system for cooling a room containing one or more computer systems housed in racks that requires "a plurality of heat exchanger units configured to receive cooling fluid through a cooling fluid line from an air conditioning unit for cooling the cooling fluid"; "a heat exchanger controller operable to control a supply of said cooling fluid to said plurality of heat exchanger units"; "an air conditioning unit controller configured to operate the air conditioning unit to vary the temperature of said cooling fluid delivered to the one or more locations in the room"; and "a plurality of pumps configured to

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control cooling fluid delivery to respective ones of said plurality of heat exchanger units, wherein said heat exchanger controller is operable to control said plurality of pumps to thereby individually control the mass flow rate of cooling fluid delivered into each of the respective heat exchanger units." Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet these limitations of claim 10 of the '287 Patent.

90. As another example, independent claim 14 recites a system for cooling a room containing one or more computer systems that requires "a plurality of heat exchanger units configured to receive cooling fluid through a cooling fluid line from an air conditioning unit for cooling the cooling fluid"; "a heat exchanger controller operable to control a supply of said cooling fluid to said plurality of heat exchanger units"; and "a plurality of valves configured to meter the flow of cooling fluid through each of said plurality of heat exchanger units positioned along respective cooling fluid lines generally upstream of respective heat exchanger units, wherein said heat exchanger controller is operable to individually control the mass flow rate of said cooling fluid through said plurality of valves." Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet these limitations of claim 14 of the '287 Patent.

91. As another example, independent claim 16 recites a system for cooling computer systems housed in one or more racks maintained in a room that requires "means for receiving air from the room, said means for receiving air being located at a plurality of locations of the room"; "means for receiving cooling fluid from an air conditioning unit"; and "means for individually manipulating a mass flow rate of the cooling fluid supplied to the plurality of means for receiving air, wherein the means for individually manipulating varies the mass flow rate of cooling fluid supplied to each of the plurality of means for receiving air in substantially independent manners."

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Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet these limitations of claim 16 of the '287 Patent.

92. As another example, independent claim 20 recites computer readable storage medium programmed to implement a cooling method for a room configured to house computer systems and comprising instructions for "supplying a plurality of heat exchanger unit configured to receive air from the room and to deliver air to the room with cooling fluid from an air conditioning unit"; "cooling said received air through heat exchange with the cooling fluid in the plurality of heat exchanger units"; and "individually manipulating a mass flow rate of the cooling fluid supplied to the each of the plurality of heat exchanger units." Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet these limitations of claim 20 of the '287 Patent.

93. For at least these reasons, Vertiv's products, including its Liebert cooling units and Liebert iCOM control systems, do not infringe the '287 Patent.

94. Vertiv is entitled to a declaratory judgment that its products, including its Liebert cooling units and Liebert iCOM control systems, have not infringed and do not infringe, either directly or indirectly, literally under the doctrine of equivalents, any claim of the '287 Patent.

COUNT III
(Declaratory Judgment of Non-Infringement of the '179 Patent)

95. Vertiv repeats and realleges paragraphs 1 through 72 hereof, as if fully set forth herein.

96. Valtrus has asserted that it is the owner of the '179 Patent.

97. Valtrus has alleged that products of Vertiv, including Liebert cooling units and Liebert iCOM control systems, infringe the '179 Patent.

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98. As a result of the acts described in the preceding paragraphs, there exists a controversy of sufficient immediacy and reality regarding whether Vertiv's products infringe any claims of the '179 Patent to warrant the issuance of a declaratory judgment of non-infringement.

99. A judicial declaration is necessary and appropriate so that Vertiv may ascertain its rights regarding its Liebert cooling and iCOM products and the '179 Patent.

100. Vertiv products (including Liebert cooling units and Liebert iCOM control systems) do not infringe the '179 Patent and Vertiv has not contributed to or induced infringement of the '179 Patent because Vertiv products do not practice or embody the limitations of the claims of the '179 Patent. By way of example, neither Vertiv nor its Liebert cooling units and/or Liebert iCOM control system products has infringed or infringes the '179 Patent at least because the products do not practice a method of cooling a plurality of racks in a data center involving the steps of "opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks"; and "manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to [a] sensed temperature being outside said predetermined temperature range" as required by independent claims 1 of the '179 Patent.

101. As another example, independent claim 16 is directed to an apparatus for cooling a plurality of racks in a data center and requires "means for activating a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks" and "means for manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to [a] sensed temperature being outside said predetermined temperature range." Vertiv's

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products, including its Liebert cooling units and Liebert iCOM control system products, do not meet these limitations of claim 16 of the '179 Patent.

102. As another example, independent claim 27 of the '179 Patent is directed to a data center cooling system having a cooling device supplying cooling fluid to racks and a plenum in fluid communication with a fan of the cooling device for conveying the cooling fluid to the racks. Claim 27 further requires "a controllable partition located within said plenum, wherein pressure of said cooling fluid in said plenum is controlled by modulation of said partition." Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet this limitation of claim 27 of the '179 Patent.

103. For at least these reasons, Vertiv's products, including its Liebert cooling units and Liebert iCOM control systems, do not infringe the '179 Patent.

104. Vertiv is entitled to a declaratory judgment that its products, including its Liebert cooling units and Liebert iCOM control systems, have not infringed and do not infringe, either directly or indirectly, literally under the doctrine of equivalents, any claim of the '179 Patent.

COUNT IV
(Declaratory Judgment of Non-Infringement of the '870 Patent)

105. Vertiv repeats and realleges paragraphs 1 through 72 hereof, as if fully set forth herein.

106. Valtrus has asserted that it is the owner of the '870 Patent.

107. Valtrus has alleged that products of Vertiv, including Liebert cooling units and Liebert iCOM control systems, infringe the '870 Patent.

108. As a result of the acts described in the preceding paragraphs, there exists a controversy of sufficient immediacy and reality regarding whether Vertiv's products infringe any claims of the '870 Patent to warrant the issuance of a declaratory judgment of non-infringement.

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109. A judicial declaration is necessary and appropriate so that Vertiv may ascertain its rights regarding its Liebert cooling and iCOM products and the '870 Patent.

110. Vertiv products (including Liebert cooling units and Liebert iCOM control systems) do not infringe the '870 Patent and Vertiv has not contributed to or induced infringement of the '870 Patent because Vertiv products do not practice or embody the limitations of the claims of the '870 Patent. By way of example, neither Vertiv nor its Liebert cooling units and/or Liebert iCOM control system products has infringed or infringes the '870 Patent at least because the products do not practice a method for evaluating one or more components in a data center involving the steps of "calculating indices of air re-circulation for the one or more heat dissipating devices based upon . . . detected [heat dissipating device] inlet temperatures, [heat dissipating device] outlet temperatures and supplied air temperatures"; "determining whether the indices of air re-circulation has changed in response to the varied flow field settings [of air delivered to one or more heat dissipating devices]"; and "evaluating the one or more components based upon changes in the indices of air re-circulation for the one or more heat dissipating devices at the various flow field settings" as required by independent claims 1 of the '870 Patent.

111. As another example, independent claim 13 is directed to a computational fluid dynamics tool for evaluating components in a data center that includes a "modeling program . . . configured to calculate indices of air re-circulation of . . . one or more heat dissipating devices based upon the inlet and outlet temperatures of one or more heat dissipating devices and temperatures of air supplied by one or more CRAC units, the modeling program being further configured to calculate the indices of air re-circulation of the one or more heat dissipating devices at various flow field settings of air delivered to the one or more heat dissipating devices"; and "wherein the modeling program is further configured to evaluate the one or more components

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based upon changes in the indices of air re-circulation of the one or more heat dissipating devices." Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet these limitations of claim 13 of the '870 Patent.

112. As another example, independent claim 22 of the '870 Patent is directed to a system for evaluating one or more components in a data center having one ore heat dissipating devices and respective inlet and outlet temperature sensors and one or more computer room air conditioning units having supply air temperature sensors. The system of claim 22 further requires "a controller configured to calculate indices of air re-circulation for the one or more heat dissipating devices based upon temperatures detected by the inlet and outlet temperature sensors and the supply air temperature sensors at various volume flow field settings of air delivered to the one or more heat dissipating devices, wherein the controller is further configured to evaluate the one or more components in the data center based upon changes in the air re-circulation indices." Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet this limitation of claim 22 of the '870 Patent.

113. As another example, independent claim 32 of the '870 Patent is directed to a system for evaluating one or more components in a data center having means for detecting inlet and outlet temperatures of one or more heat dissipating devices and means for detecting temperatures of air supplied by one or more computer room air conditioning units. The system of claim 32 further requires "means for calculating indices of air re-circulation for the one or more heat dissipating devices at various flow field settings of air delivered to the one or more heat dissipating devices"; and "means for evaluating the one or more components based upon the calculated indices of air re-circulation at the various flow field settings." Vertiv's products, including its Liebert cooling

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units and Liebert iCOM control system products, do not meet these limitations of claim 32 of the '870 Patent.

114. As another example, independent claim 37 of the '870 Patent recites computer readable storage medium containing one or more embedded computer programs implementing a method for evaluating one or more components in a data center and comprising instructions for "calculating indices of air re-circulation for the one or more racks at various flow field settings of air delivered to the one or more heat dissipating devices" and "evaluating the one or more components based upon the calculated indices of air re-circulation at the various flow field settings." Vertiv's products, including its Liebert cooling units and Liebert iCOM control system products, do not meet these limitations of claim 37 of the '870 Patent.

115. For at least these reasons, Vertiv's products, including its Liebert cooling units and Liebert iCOM control systems, do not infringe the '870 Patent.

116. Vertiv is entitled to a declaratory judgment that its products, including its Liebert cooling units and Liebert iCOM control systems, have not infringed and do not infringe, either directly or indirectly, literally under the doctrine of equivalents, any claim of the '870 Patent.

COUNT FIVE
(Declaratory Judgment of Non-Infringement of the '490 Patent)

117. Vertiv repeats and realleges paragraphs 1 through 72 hereof, as if fully set forth herein.

118. Valtrus has asserted that it is the owner of the '490 Patent.

119. Valtrus has alleged that products of Vertiv, including Liebert cooling units and Liebert modular sensors, infringe the '490 Patent.

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120. As a result of the acts described in the preceding paragraphs, there exists a controversy of sufficient immediacy and reality regarding whether Vertiv's products infringe any claims of the '490 Patent to warrant the issuance of a declaratory judgment of non-infringement.

121. A judicial declaration is necessary and appropriate so that Vertiv may ascertain its rights regarding its Liebert cooling units and modular sensor products and the '490 Patent.

122. Vertiv products (including Liebert cooling units and Liebert modular sensors) do not infringe the '490 Patent and Vertiv has not contributed to or induced infringement of the '490 Patent because Vertiv products do not practice or embody the limitations of the claims of the '490 Patent. By way of example, neither Vertiv nor its Liebert cooling units and/or Liebert modular sensor products has infringed or infringes the '490 Patent at least because the products do not include a modular sensor assembly that comprises "an elongate flexible body, configured to attach to a computer rack"; and "a plurality of addressable sensors, disposed along the body and interconnected to a common connector wire" as required by independent claims 1 of the '490 Patent.

123. As another example, independent claim 11 is directed to a sensor system that includes "a modular sensor assembly, having a flexible elongate body, attached to [a] computer rack"; and "a plurality of addressable sensors, disposed along the elongate body of the modular sensor assembly, and interconnected in parallel to a common connector wire, configured to independently measure an environmental condition in the immediate vicinity of the sensor." Vertiv's products, including its Liebert cooling units and Liebert modular sensor products, do not meet these limitations of claim 11 of the '490 Patent.

124. As another example, independent claim 28 of the '490 Patent is directed to a computer rack system that includes "a modular sensor assembly, attached to the rack body,

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comprising an elongate flexible sensor body having a plurality of addressable sensors connected in parallel to a common connector wire, each sensor being configured to generate a digital signal representative of an environmental condition"; and "a connector board, associated with the rack body, interconnected to the connector wire and to a central computer system configured to receive data from the plurality of sensors and to monitor environmental conditions associated with the rack." Vertiv's products, including its Liebert cooling units and Liebert modular sensor products, do not meet this limitation of claim 28 of the '490 Patent.

125. For at least these reasons, Vertiv's products, including its Liebert cooling units and Liebert modular sensor products, do not infringe the '490 Patent.

126. Vertiv is entitled to a declaratory judgment that its products, including its Liebert cooling units and Liebert modular sensor products, have not infringed and do not infringe, either directly or indirectly, literally under the doctrine of equivalents, any claim of the '490 Patent.

JURY DEMAND

127. Vertiv hereby demands a trial by jury on all issues.

PRAYER FOR RELIEF

WHEREFORE, Vertiv requests this Court to enter judgment in Vertiv's favor and against Valtrus as follows:

128. A declaration that neither Vertiv nor its products have infringed or do infringe, under any theory of infringement (including directly (whether individually or jointly) or indirectly (whether contributorily or by inducement)) any claim of the Patents-in-Suit, literally or under the doctrine of equivalents, in violation of 35 U.S.C. § 271;

129. Injunctive relief restraining Valtrus and each of its officers, directors, agents, counsel, servants, employees, and all of persons in active concert or participation with any of them,

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or successors and enjoining them from alleging, representing, threatening, or otherwise stating that Vertiv or Vertiv products or the activities of customers, manufacturers, users, importers, or sellers in relation to Vertiv's products infringes any claims of the Patents-in-Suit or from instituting or initiating any action or proceeding alleging infringement of any claims of the Patents-in-Suit against Vertiv or any customers, manufacturers, users, importers, or sellers of Vertiv's products;

130. Declaring Vertiv as the prevailing party and this case as exceptional, and awarding Vertiv its reasonable attorneys' fees, pursuant to 35 U.S.C. § 285;

131. Ordering that Valtrus pay all reasonable attorneys' fees, expenses, and costs associated with this action; and

132. Awarding such other and further relief as this Court deems just and proper.

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Dated: May 14, 2024

Respectfully Submitted,

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EXHIBIT A

US006718277B2

(12) **United States Patent**
Sharma

(10) **Patent No.: US 6,718,277 B2**
(45) **Date of Patent: Apr. 6, 2004**

(54) **ATMOSPHERIC CONTROL WITHIN A BUILDING**

(75) Inventor: **Ratnesh Sharma**, Union City, CA (US)

(73) Assignee: **Hewlett-Packard Development Company, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/123,403**

(22) Filed: **Apr. 17, 2002**

(65) **Prior Publication Data**

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(51) **Int. Cl.**[7] **G06F 15/00**; F24F 7/007; G05D 15/00

(52) **U.S. Cl.** **702/132**; 165/80.03; 236/13; 236/49.3; 361/695; 454/229; 700/41

(58) **Field of Search** 702/132; 700/41, 700/70, 117, 205; 62/180, 205, 259.2, 263; 236/49.3; 454/187, 229, 256; 73/31.01, 31.02; 361/695

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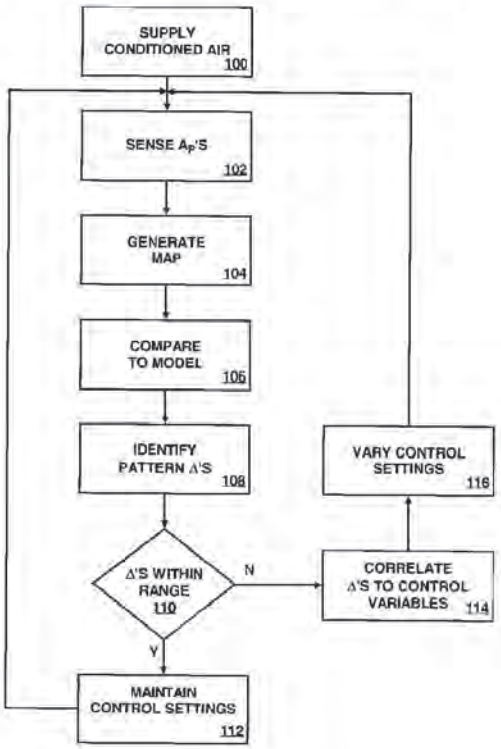
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Primary Examiner—John Barlow
Assistant Examiner—John Le

(57) **ABSTRACT**

A method and system for controlling atmospheric conditions within a building. A conditioned fluid is supplied inside of the building and one or more atmospheric parameters in various locations inside of the building are sensed. An empirical atmospheric map is then generated and compared to a template atmospheric map. Pattern differentials are identified therebetween and corrective action to reduce the pattern differentials is determined. One or more of the quantity, quality, and distribution of the conditioned fluid is varied in accord with the corrective action determination.

24 Claims, 2 Drawing Sheets



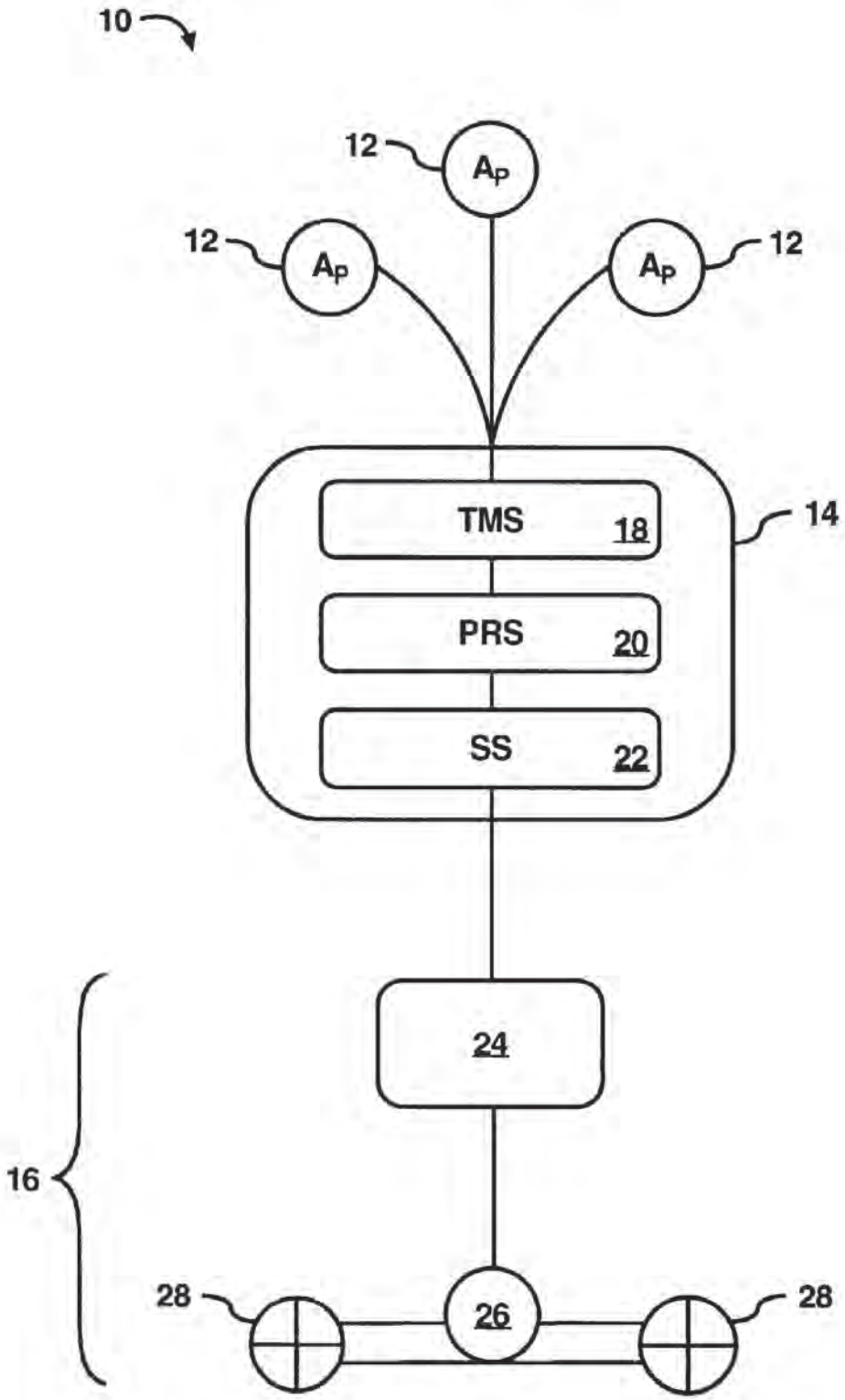


FIG. 1

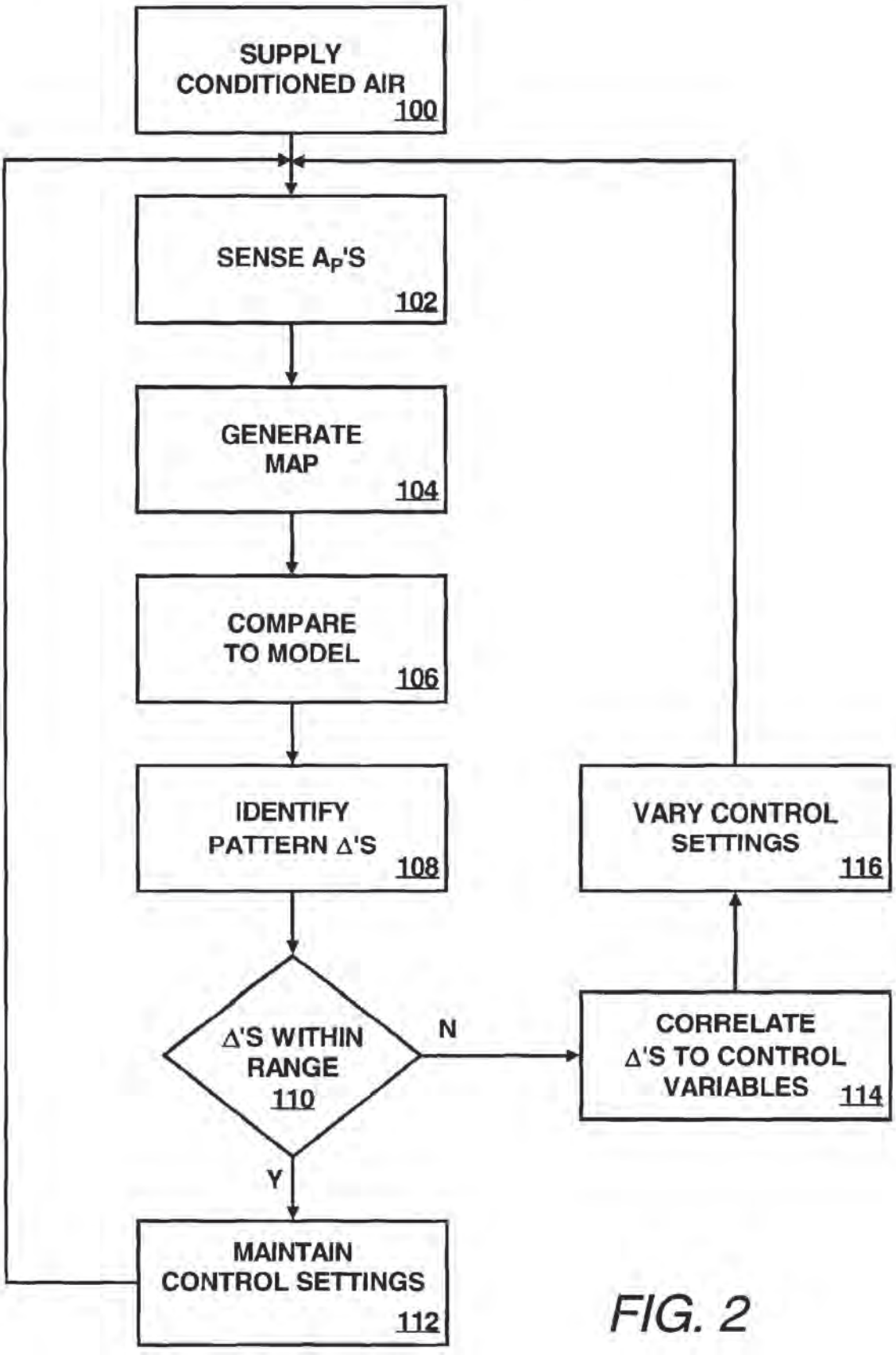

SUPPLY CONDITIONED AIR 100
SENSE A_P'S 102
GENERATE MAP 104
COMPARE TO MODEL 106
IDENTIFY PATTERN Δ'S 108
Δ'S WITHIN RANGE 110
N
Y
CORRELATE Δ'S TO CONTROL VARIABLES 114
VARY CONTROL SETTINGS 116
MAINTAIN CONTROL SETTINGS 112

FIG. 2

ATMOSPHERIC CONTROL WITHIN A BUILDING

CROSS-REFERENCES TO RELATED APPLICATIONS

The present invention is related to the following pending applications: Ser. No. 09/970,707, filed Oct. 5, 2001, and entitled "SMART COOLING OF DATA CENTERS", by Patel et al.; Ser. No. 10/076,635, filed Feb. 19, 2002, and entitled "DESIGNING LAYOUT FOR INTERNET DATA-CENTER COOLING", by Nakagawa et al; and Ser. No. 10/022,010, filed Apr. 16, 2002, and entitled "DATA CENTER ENERGY MANAGEMENT", by Friedrich et al. Each of the above listed cross-references is assigned to the assignee of the present invention and is incorporated by reference herein.

BACKGROUND

The present invention relates to controlling atmospheric conditions within a building. One type of building is a data center that houses numerous electronic packages. Each electronic package is arranged in one of a plurality of racks distributed throughout the data center. A rack may be defined as an Electronics Industry Association (EIA) enclosure and may be configured to house a number of personal computer (PC) boards. The PC boards typically include a number of electronic packages, such as processors, micro-controllers, high speed video cards, memories, semi-conductor devices, and the like. These electronic packages dissipate relatively significant amounts of heat during the operation of the respective components. For example, a typical PC board comprising multiple microprocessors may dissipate approximately 250 W of power. Thus, a rack containing forty (40) PC boards of this type may dissipate approximately 10 KW of power.

The power required to remove the heat dissipated by the electronic packages in a given rack is generally equal to about 10 percent of the power needed to operate the packages. However, the power required to remove the heat dissipated by a plurality of racks in a data center is generally equal to about 50 percent of the power needed to operate the packages in the racks. The disparity in the amount of power required to dissipate the various heat loads between racks of data centers stems from the additional thermodynamic work needed in the data center to cool the air. Racks are typically cooled with fans that operate to move cooling fluid, such as air, across the heat dissipating components, whereas data centers often use reverse power cycles to cool heated return air. The additional work required to achieve the temperature reduction, in addition to the work associated with moving the cooling fluid in the data center and the condenser, often add up to the 50 percent power requirement mentioned above. As such, the cooling of entire data centers presents major challenges beyond those faced with the cooling of individual racks of electronic packages.

To substantially guarantee proper operation and to extend the life of the electronic packages arranged in the racks of the data center, it is necessary to maintain the temperatures of the packages within predetermined safe operating ranges. Operation at temperatures above maximum operating temperatures may result in irreversible damage to the electronic packages. In addition, it has been established that the reliabilities of electronic packages, such as semiconductor electronic devices, decrease with increasing temperature. Therefore, the heat energy produced by the electronic packages during operation must thus be removed at a rate that

ensures that operational and reliability requirements are met. Because of the relatively large size of data centers and the high number of electronic packages contained therein, it is often expensive to cool data centers within the predetermined temperature ranges.

Data centers are typically cooled by operation of one or more air conditioning units. The compressors of the air conditioning units typically require a minimum of about thirty (30) percent of the required cooling capacity to sufficiently cool the data centers. The other components, such as condensers, air movers (fans), etc., typically require an additional twenty (20) percent of the required cooling capacity. For example, a high density data center with 100 racks, each rack having a maximum power dissipation of 10 KW, generally requires 1 MW of cooling capacity. Air conditioning units with a capacity of 1 MW of heat removal generally require a minimum of 300 KW input compressor power in addition to the power needed to drive the air moving devices, e.g., fans, blowers, etc.

Conventional data center air conditioning units do not vary their cooling output based on the distributed, location-specific needs of the data center. Typically, the distribution of work among the operating electronic components in the data center is random and is not controlled. Because of work distribution, some components in one location of the data center may be operating at a maximum capacity, while other components in another location of the data center may be operating at various power levels below a maximum capacity. Furthermore, conventional cooling systems typically operate at 100 percent of capacity on a continuous basis, thereby cooling all electronic packages, regardless of need. In other words, data centers are air conditioned on an overall, room-level basis, thereby yielding unnecessarily high operating expenses to sufficiently cool the heat generating components contained in the racks of data centers. Moreover, prior art attempts at cooling use relatively inaccurate and unsophisticated methods of monitoring and adjusting temperature distribution that result in less than optimal data center cooling efficiency.

BRIEF SUMMARY OF THE INVENTION

According to one embodiment of the present invention, there is provided a method of controlling atmospheric conditions within a building. The method includes the steps of supplying a conditioned fluid inside of the building and sensing one or more atmospheric parameters in various locations inside of the building. From the results of the sensing step, an empirical atmospheric map is then generated and compared to a template atmospheric map. Pattern differentials are identified between the empirical and template atmospheric maps, and corrective action is determined to reduce the pattern differentials. Finally, one or more of the quantity, quality, and distribution of the conditioned fluid is varied. According to another aspect of the present invention, there is provided a system for carrying out an embodiment of the method of the present invention.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Features and advantages of the present invention will become apparent to those skilled in the art from the following description with reference to the drawings, in which:

FIG. **1** is a schematic illustration of an embodiment of a system of the present invention; and

FIG. **2** is a flow chart of an embodiment of a method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is not limited in its application to the details of any particular arrangement described or shown, since the present invention is capable of multitudes of embodiments without departing from the spirit and scope of the present invention. First, the principles of the present invention are described by referring to only a limited number of embodiments for simplicity and illustrative purposes. Although only a limited number of embodiments of the invention are particularly disclosed herein, one of ordinary skill in the art would readily recognize that the same principles are equally applicable to, and can be to implemented in all types of atmospheric control systems. Furthermore, numerous specific details are set forth to convey with reasonable clarity the inventor's possession of the present invention, how to make and/or use the present invention, and the best mode in carrying out the present invention known to the inventor at the time of application. It will, however, be apparent to one of ordinary skill in the art that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention. Finally, the terminology used herein is for the purpose of description and not of limitation. Thus, the following detailed description is not to be taken in a limiting sense and the scope of the present invention is defined by the claims and their equivalents.

Generally in accord with the present invention, a method and related system are configured to control one or more atmospheric conditions within a building. More specifically, the method and system are configured to adjust one or more of the quantity, quality, and distribution of a conditioned fluid throughout a data center. The method and system are configured to accomplish such control based upon atmospheric mapping and pattern recognition; using as input, one or more atmospheric parameters measured at various, discrete sensor locations throughout the data center.

In accord with one embodiment of the present invention, the amount of energy typically required to cool a data center may be relatively reduced by strategically distributing cooling fluid, or conditioned air, within the data center by substantially favoring or increasing the cooling fluid flow to locations within the data center having racks that dissipate greater amounts of heat, and by substantially disfavoring or decreasing the cooling fluid flow to locations having racks that dissipate lesser amounts of heat. Thus, instead of operating devices, e.g., compressors, fans, etc., of the cooling system at substantially 100 percent of the anticipated heat dissipation from the racks, those devices may be operated according to the actual location and area specific cooling needs. In addition, the racks may be positioned throughout the data center according to their anticipated heat loads to thereby enable computer room air conditioning (CRAC) units located at various positions throughout the data center to operate in a more efficient manner. In another respect, the positioning of the racks and cooling strategy may be determined through implementation of modeling and metrology of the cooling fluid flow throughout the data center. In addition, the numerical modeling may be implemented to determine the volume flow rate and velocity of the cooling fluid flow through the data center.

Referring specifically in detail to the Figures, there is shown in FIG. **1** a schematic view of the system **10** that may be used in accordance with an embodiment of the present

invention. The system **10** generally includes atmospheric sensors **12**, a central processing unit (CPU) **14**, and an atmospheric control system **16**. The atmospheric control system **16** can be a smart cooling system, exemplified by copending U.S. patent application Ser. No. 09/970,707, filed on Oct. 5, 2001, by Patel et al., assigned to the assignee hereof, and incorporated by reference herein in its entirety. Alternatively, it is contemplated that any type of system directed at controlling atmospheric conditions could be employed, including air-conditioner systems, humidifier systems, filtering systems, fire suppression systems, etc.

The atmospheric sensors **12** are used for measuring one or more atmospheric parameter and encompass temperature sensors, such as thermocouples, temperature transducers, thermistors, or the like. The atmospheric sensors **12** could also include humidity sensors, barometric or pressure sensors, fluid velocity sensors, particle sensors, smoke sensors, and the like. The atmospheric sensors **12** are located throughout the portions of a data center type of building (not shown) that are desired to be atmospherically controlled. Specifically, the atmospheric sensors **12** can be positioned in a variety of ways. For example, the atmospheric sensors **12** could be dispersed randomly in various locations and elevations, or aligned according to a predetermined coordinate grid, or placed in alignment with locations of vents and/or racks, or placed in accordance with the recommendations from a computational fluid dynamics model. In any case, it is contemplated that very large data centers, measured in the tens of thousands of square feet, may require thousands of atmospheric sensors **12** spread throughout. The atmospheric sensors **12** are electronically communicated with the CPU **14** either through wiring or via wireless telemetry. In any case, the CPU **14** is capable of keeping track of the location of each atmospheric sensor **12** such that the output of each can be "mapped".

The CPU **14** can be a stand-alone personal computer, a computer board or boards docked within one of the racks in the data center, a computer chip, etc., regardless, the CPU **14** includes various software that is loaded thereto. First, the CPU **14** includes software for generating maps of atmospheric conditions, such as thermal mapping software **18**. Thermal mapping software **18** is capable of processing thousands of input data points, such as thousands of sensor signals, and outputting map-like information. For example, a thermal map is composed of temperature contours that define various isothermal regions, or isotherms, of distinct temperatures. The most severe of these isotherms are commonly known as "hot spots". Hot spots may not necessarily correspond in exact location to any given temperature sensor, but may be located between various temperature sensors. Nevertheless, thermal mapping software can extrapolate or triangulate the location of the actual hot spot from the known locations of the temperature sensors. So, if temperature sensors are located in a range of elevations in various latitudinal and longitudinal coordinate positions of a data center, the thermal mapping software can triangulate not only the coordinate position of a hot spot, but also the elevation thereof. The temperature sensor readings provide temperature data and data for calculating temperature gradients, which are used to create a thermal map. In the absence of accurate or comprehensive temperature data, temperature gradients can be used to locate hot spots in the data center by mathematical optimization techniques like steepest gradient, etc. In general, triangulation presents a relatively accurate and efficient approximation technique and, thus, it is possible to use fewer, more sparsely distributed temperature sensors to save on equipment expense and failure modes if desired.

Second, the CPU **14** includes software for recognizing pattern differentials in such maps, more commonly known as pattern recognition software **20**. Such software basically involves a decoding process in which discriminations in patterns are made without human intervention. Third, strategic software **22** is loaded on the CPU **14** and is used to determine a course of corrective action to minimize or eliminate the pattern differentials by accepting output of the mapping software **18**, processing it, and outputting commands to the cooling system **16**. It is contemplated that commercial, general purpose mathematical optimization software like MATLAB could be adapted to generate thermal maps and identify hot spots by pattern recognition. It is also contemplated at this time that application-specific neural network algorithms can also be used to do the same.

In response, the cooling system **16** is used to vary one or more of the quantity, quality, and distribution of the cooling fluid used to cool the data center. The cooling system **16** encompasses a chiller unit **24**, but those skilled in the art will recognize that multitudes of other types of cooling systems are generally well-known and available for use with the present invention including, for example, refrigeration systems, cooling tower systems, cooler-condenser systems, and the like. In any case, the cooling system **16** also includes one or more variable-speed air movers or blowers **26**, and one or more remotely controlled dampers or vents **28**. Those skilled in the art will recognize that ventilation structure connecting the blower, vents, etc. are well known in the relevant art of Heating, Ventilating, and Air Conditioning (HVAC).

It is possible to vary any combination of cooling system control variables to change the quantity, quality, and/or distribution of the cooling fluid and thereby adjust the atmospheric conditions within the data center. For example, chiller cycle can be increased or decreased between 0% and 100% of operating capacity to change the cooling quality of the cooling fluid, i.e. temperature, humidity, particulate count, etc. To change the quantity of cooling fluid, such as conditioned air, the speed and/or baffling of the blower **26** can be adjusted, and the percentage opening of the vents **28** can be varied, either individually or collectively. Also, if the vents **28** include individual blowers (not shown), such blowers could also be adjusted in speed. To change the distribution of conditioned air, one or more of multiple chillers, blowers, and vents can be strategically adjusted to target one or more hot spot locations within the data center. For example, if one corner of the data center is demanding the most significant portion of the cooling needs of the entire data center, then the most proximate chiller(s), blower(s), and vent(s) can be selected, while the other, relatively distant chiller(s), blower(s), and vent(s) can be deactivated or reduced. It is contemplated that any other reasonably foreseen atmospheric control system control variables could also be adjusted.

Referring now to FIG. **2**, in addition to the embodiment described above, an embodiment of a method of the present invention involves cooperation of the CPU between the temperature sensors and the cooling system. The method of the present invention could also be practiced using other systems besides the one disclosed herein, and thus is not limited thereby. The system disclosed herein is simply one of many possible physical manifestations of the method. As discussed previously, the cooling system supplies a cooling fluid within the data center to cool the equipment within the data center, as shown in block **100**. In block **102**, the temperature within the data center is sensed in various locations and is communicated to the CPU.

The thermal mapping software converts the point-specific temperature sensor data into information by generating an empirical thermal map therefrom, as depicted in block **104**. As discussed above, a thermal map can triangulate hot spots from discrete sensor locations based on mathematical optimization techniques. Hot spots are known to arise in several situations, for example, where electronic packages in a given rack draw exceptional amounts of power due to exceptionally high usage of those packages, and the data center cooling system cannot supply enough conditioned fluid to alleviate the overheating. Hot spots may also arise when racks output normal amounts of heat, but the data center cooling system is malfunctioning in a specific location, or in general.

The thermal mapping step may be executed on an instantaneous, snapshot, or sampling basis but, alternatively, this step may be done on a real-time basis. It is also contemplated that the thermal map could be generated directly, without discrete temperature sensors, using thermography technology, based on infrared detection of heat that is emitted by the equipment in the data center. It is further contemplated that the thermal map could be generated by estimating temperature as a function of the power draw to the electronic packages and/or racks within the data center. Thus, the temperature sensing and map generating steps could be accomplished with thermographic equipment and software, or inferring temperature from power draw.

The thermal map also provides a powerful visual tool for a data center operator. A typical data center is a highly thermally interdependent environment where thermal performance of each electronic package of each rack affects performance of neighboring packages and racks to various orders of magnitude. Thus, a thermal map also provides a pictorially informative way of identifying the thermal interdependencies across the data center landscape.

As shown in block **106**, the pattern recognition software compares the empirical thermal map to a template thermal map. The template thermal map could also be termed a master, or model thermal map. The template basically represents a thermal map of an optimally operating data center cooling system. The template can be dynamic, generated either in real-time from current operating conditions, or can be static, generated prior to the comparing step **106**. Computational fluid dynamics (CFD) software tools, such as FLOVENT/AIRPACK, are widely available and known to those skilled in the art. The CFD tool accepts various inputs for modeling, including heat loads from the racks within the data center, velocity of the cooling fluid flowing throughout the data center, temperature, pressure, and the like in the data center. CFD modeling can be used in the design and layout of a data center, suggesting locations for racks and vents. Alternatively, CFD modeling can be used to output a master, template, or model thermal map to be emulated by adjusting cooling system variables. Instructive in this regard is U.S. patent application Ser. No. 10/076,635, filed on Feb. 19, 2002, and entitled "DESIGNING LAYOUT FOR INTERNET DATACENTER COOLING", by Nakagawa et al., assigned to the assignee hereof and incorporated by reference herein in its entirety.

After, or while, the empirical thermal map is compared to the model thermal map, the pattern recognition software is also applied to recognize pattern differentials therebetween, as depicted in block **108**. Pattern recognition is also commonly referred to as template matching, masking, etc. For example, in the case of data center cooling, thermal hot spots can be identified. Once identified, an initial classification step occurs as depicted by block **110**. Certain isotherms may

exceed a predetermined range of temperature, size, etc., and thus can be targeted for elimination or reduction. Alternatively, if all isotherms are within the predetermined range of temperature, size, etc., then the cooling system simply maintains current operating conditions and settings, as depicted in block **112**.

Upon recognizing the pattern differentials, the strategic software is used to determine the corrective action required to eliminate or at least reduce pattern differentials within the data center, as depicted in block **114**. Control variable data, such as the location of the vents, the capacity of the blower, and the capacity of the chiller, are used to determine how most efficiently to cool the data center. In addition, the thermal map data is also used, such as the location, size, and intensity of the isotherms. Specifically, the above-mentioned data sets are correlated to develop an optimally efficient course of corrective action.

In block **116**, based on the corrective action selected, one or more of the quantity, quality, and distribution of the conditioned fluid of the cooling system is varied. For example, if the size and/or intensity of an hot spot isotherm is relatively small, then the cooling system can merely adjust the opening size of the vent closest to the location of the isotherm. If, on the other hand, the size and/or intensity of an isotherm is relatively large, then multiple vents can be adjusted in addition to increasing the chiller cycle. Similarly, if the cooling system included multiple chillers, the chiller most proximate the isotherm could be increased in cycle. In general, the quantity and/or quality of the cooling fluid can be decreased, or maintained, for locations of the data center that exhibit pattern differentials within a predetermined acceptable range. In contrast, the quantity and/or quality of the cooling fluid may be increased for locations of the data center that exhibit pattern differentials outside of a predetermined acceptable range. Finally, the method is carried out such that the temperature sensing step through the step of varying the conditioned air can be a continuous loop.

Those of ordinary skill in the art will recognize that the present invention is capable of substantially reducing the energy consumption associated with cooling a data center, by virtue of using directed, location-specific cooling instead of diffused, room-level cooling. More particularly, the cooling system can be operated relatively more efficiently compared to the prior art by virtue of a more precise method of tracking and using actual temperature measurement as an input to cooling system control. In other words, the present invention provides methodology for extracting a large amount of discrete, location-specific temperature data points and converting same into more continuous, fluid-like information in the form of a thermal map. The present invention is suited for use with applications requiring thousands of sensors, or even just a few well-placed sensors. Regardless, the present invention enables use of the spaces between the sensor locations to be included in assessing or triangulating the locations, size, and intensity of hot spots, resulting in more accurate hot spot reduction than the prior art allows for. Therefore, compared to the prior art and for a given size data center, the present invention presents a more accurate and efficient cooling method, thus requiring fewer and smaller cooling devices and less energy consumption.

While the present invention has been described in terms of a limited number of embodiments, it is apparent that other forms could be adopted by one skilled in the art. In other words, the teachings of the present invention encompass any reasonable substitutions or equivalents of claim limitations. For example, other modes of carrying out the method steps could be used in addition to those described here, and the method could be practiced independently of the specific system disclosed herein. Those skilled in the art will appreciate that other applications, including those outside of data center cooling, are possible with this invention. Accordingly, the present invention is not limited to only cooling of data centers, but rather applies broadly to many other environmental control systems, including particulate filtering, HVAC, etc. Accordingly, the scope of the present invention is to be limited only by the following claims.

What is claimed is:

1. A method of controlling atmospheric conditions within a building, said method comprising the steps of:

supplying a conditioned fluid inside said building;

sensing at least one atmospheric parameter in a plurality of locations inside said building;

generating an empirical atmospheric map from the results of said sensing step;

comparing said empirical atmospheric map to a template atmospheric map; and

identifying pattern differentials between said empirical and template atmospheric maps.

2. The method as claimed in claim **1**, further comprising the steps of:

determining corrective action to reduce said pattern differentials; and

varying at least one of the quantity, quality, and distribution of said conditioned fluid in accord with said determining step.

3. The method as claimed in claim **2**, wherein said supplying step comprises the step of operating a system having at least one of a plurality of vents, at least one blower, and at least one source of conditioned air.

4. The method as claimed in claim **3**, wherein said determining step comprises correlating at least one of the location, size, and intensity of said pattern differentials to at least one of the location of said plurality of vents, the speed of said at least one blower, and the capacity of said at least one source of conditioned air.

5. The method as claimed in claim **4**, wherein said varying step comprises adjusting at least one of the opening of said plurality of vents, the speed of said at least one blower, and the output of said at least one source of conditioned air.

6. The method as claimed in claim **1**, wherein said generating step comprises using thermal mapping software to process input from said sensing step and to produce output in the form of said empirical atmospheric map.

7. The method as claimed in claim **1**, wherein said identifying step comprises using pattern recognition software.

8. The method as claimed in claim **1**, wherein said plurality of locations of said sensing step comprises locations at various elevations within said building.

9. The method as claimed in claim **1**, wherein said sensing step comprises using at least one of temperature sensors, humidity sensors, pressure sensors, particle sensors, smoke sensors, and velocity sensors.

10. The method as claimed in claim **1**, wherein the step of generating an empirical atmospheric map comprises generating a map composed of temperature contours that define various isothermal regions.

11. The method as claimed in claim **1**, wherein the step of identifying pattern differentials between said empirical and template atmospheric maps comprises performing at least one of extrapolation and triangulation to determine locations of one or more hot spots.

12. A method of cooling a data center having equipment therein, said method comprising the steps of:

supplying a cooling fluid within said data center to cool said equipment within said data center;

sensing temperature within said data center in a plurality of locations;

generating an empirical thermal map of said data center from the results of said sensing step;

comparing said empirical thermal map to a template thermal map; and

identifying pattern differentials between said empirical and template thermal maps.

13. The method as claimed in claim **12**, further comprising the steps of:

determining corrective action to reduce said pattern differentials; and

varying at least one of the quantity, quality, and distribution of said cooling fluid in accord with said determining step.

14. The method as claimed in claim **13**, wherein said supplying step comprises operating a system having at least one of a plurality of vents, at least one blower, and at least one source of conditioned air.

15. The method as claimed in claim **14**, wherein said determining step comprises correlating at least one of the location, size, and intensity of said pattern differentials to at least one of the location of said plurality of vents, the speed of said at least one blower, and the capacity of said at least one source of conditioned air.

16. The method as claimed in claim **15**, wherein said varying step comprises adjusting at least one of the opening of at least one of said plurality of vents, the speed of said at least one blower, and the output of said at least one source of conditioned air.

17. The method as claimed in claim **12**, wherein said generating step comprises using thermal mapping software to process input from said sensing step and to produce output in the form of said empirical atmospheric map, wherein said thermal mapping software triangulates locations of hot spots.

18. The method as claimed in claim **12**, wherein said identifying step comprises using pattern recognition software.

19. The method as claimed in claim **12**, wherein said plurality of locations of said sensing step comprises locations at various elevations within said data center.

20. The method as claimed in claim **12** wherein the step of generating an empirical atmospheric map comprises generating a map composed of temperature contours that define various isothermal regions.

21. The method as claimed in claim **12**, wherein the step of identifying pattern differentials between said empirical and template atmospheric maps comprises performing at least one of extrapolation and triangulation to determine locations of one or more hot spots.

22. A system for controlling atmospheric conditions within a building, said system comprising:

means for supplying a conditioned fluid inside said building;

means for sensing at least one atmospheric parameter in a plurality of locations inside said building;

means for generating an empirical atmospheric map from said means for sensing;

means for comparing said empirical atmospheric map to a template atmospheric map; and

means for identifying characteristics of pattern differentials between said empirical and template atmospheric maps, said characteristics comprising at least one of location, size, and intensity of said pattern differentials.

23. The system as claimed in claim **22**, further comprising:

means for determining corrective action to reduce said pattern differentials; and

means for varying at least one of the quantity, quality, and distribution of said conditioned fluid in accord with said means for determining corrective action.

24. The system as claimed in claim **23**, wherein said means for supplying comprises an air-conditioning system having at least one of a plurality of vents, at least one blower, and at least one source of conditioned air, further wherein said means for determining comprises means for correlating at least one of the location, size, and intensity of said pattern differentials to at least one of the respective location of said plurality of vents, the speed of said at least one blower, and the capacity of said at least one source of conditioned air, and also wherein said means for varying comprises means for adjusting at least one of said plurality of vents, said at least one blower speed, and said at least one source of conditioned air output, wherein said generating means triangulates hot spots from said sensing means.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,718,277 B2
DATED : April 6, 2004
INVENTOR(S) : Sharma

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Columns 8, 9 and 10,
Please replace claims 1, 12, 17, and 22 with the following claims:

1. A method of controlling atmospheric conditions within a building, said method comprising the steps of:
supplying a conditioned fluid inside said building;
sensing at least one atmospheric parameter in a plurality of locations inside said building;
generating an empirical atmospheric map from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical atmospheric map;
comparing said empirical atmospheric map to a template atmospheric map; and
identifying pattern differentials between said empirical and template atmospheric maps.

12. A method of cooling a data center having equipment therein, said method comprising the steps of:
supplying a cooling fluid within said data center to cool said equipment within said data center;
sensing temperature within said data center in a plurality of locations;
generating an empirical thermal map of said data center from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical thermal map; comparing said empirical thermal map to a template thermal map; and
identifying pattern differentials between said empirical and template thermal maps.

17. The method as claimed in claim 12, wherein said generating step comprises using thermal mapping software to process input from said sensing step and to produce output in the form of said empirical thermal map, wherein said thermal mapping software triangulates locations of hot spots.

22. A system for controlling atmospheric conditions within a building, said system comprising:
means for supplying a conditioned fluid inside said building;
means for sensing at least one atmospheric parameter in a plurality of locations inside said building;
means for generating an empirical atmospheric map from said means for sensing, wherein the means for generating comprises software for processing input from said means for sensing and for producing output in the form of said empirical atmospheric map;

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,718,277 B2
DATED : April 6, 2004
INVENTOR(S) : Sharma

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

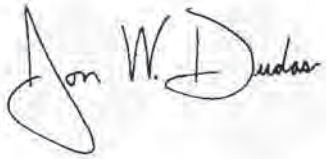
Claim 22, cont'd.,

means for comparing said empirical atmospheric map to a template atmospheric map; and

means for identifying characteristics of pattern differentials between said empirical and template atmospheric maps, said characteristics comprising at least one of location, size, and intensity of said pattern differentials.

Signed and Sealed this

Sixteenth Day of November, 2004



JON W. DUDAS
Director of the United States Patent and Trademark Office

EXHIBIT B

US006854287B2

(12) **United States Patent**
Patel et al.

(10) **Patent No.: US 6,854,287 B2**
(45) **Date of Patent: Feb. 15, 2005**

(54) **COOLING SYSTEM**

(75) Inventors: **Chandrakant D. Patel**, Fremont, CA (US); **Cullen E. Bash**, San Francisco, CA (US)

(73) Assignee: **Hewlett-Packard Development Company, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/697,697**

(22) Filed: **Oct. 31, 2003**

(65) **Prior Publication Data**

US 2004/0089011 A1 May 13, 2004

Related U.S. Application Data

(62) Division of application No. 10/210,040, filed on Aug. 2, 2002.

(51) **Int. Cl.**[7] **F25D 23/12**

(52) **U.S. Cl.** **62/259.2**; 62/185; 62/201; 361/696

(58) **Field of Search** 62/259.2, 201, 62/229, 185, 186, 157, 208, 178, 180; 361/696

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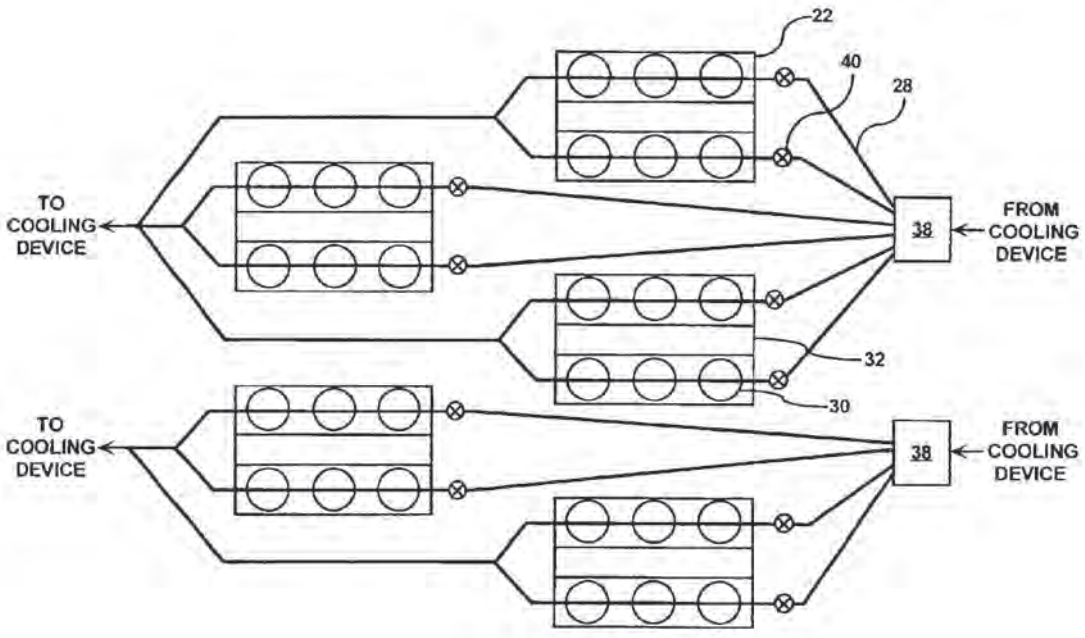
* cited by examiner

Primary Examiner—Marc Norman

(57) **ABSTRACT**

A system and method for cooling a room configured to house a plurality of computer systems. A heat exchanger unit is configured to receive air from the room and to deliver air to the room. The heat exchanger unit is supplied with cooling fluid operable to cool the received air in the heat exchanger unit. At least one of the temperature of the cooling fluid supplied to the heat exchanger unit and the air delivery to the room may be controlled in response to temperatures sensed at one or more locations in the room.

22 Claims, 5 Drawing Sheets



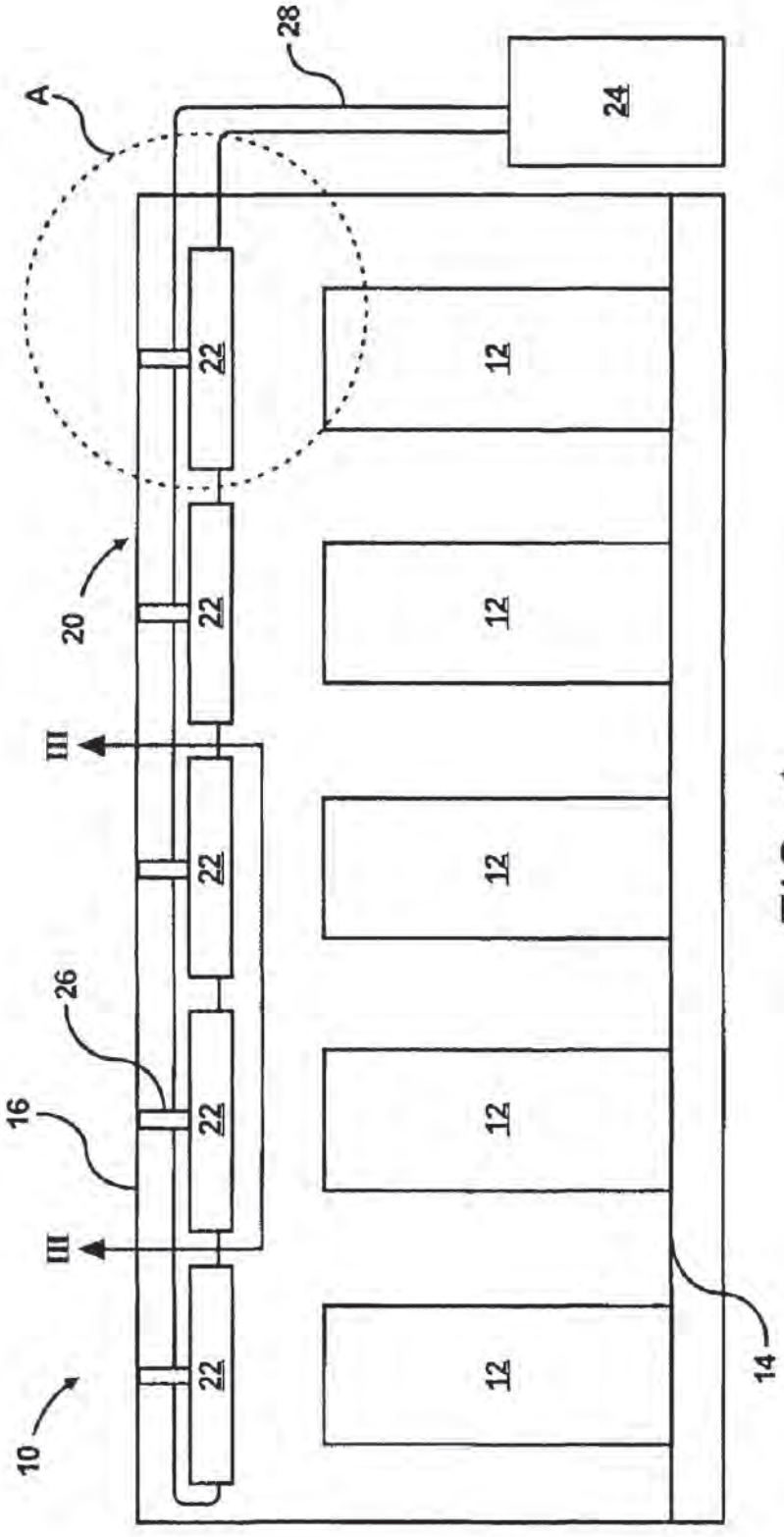


FIG. 1

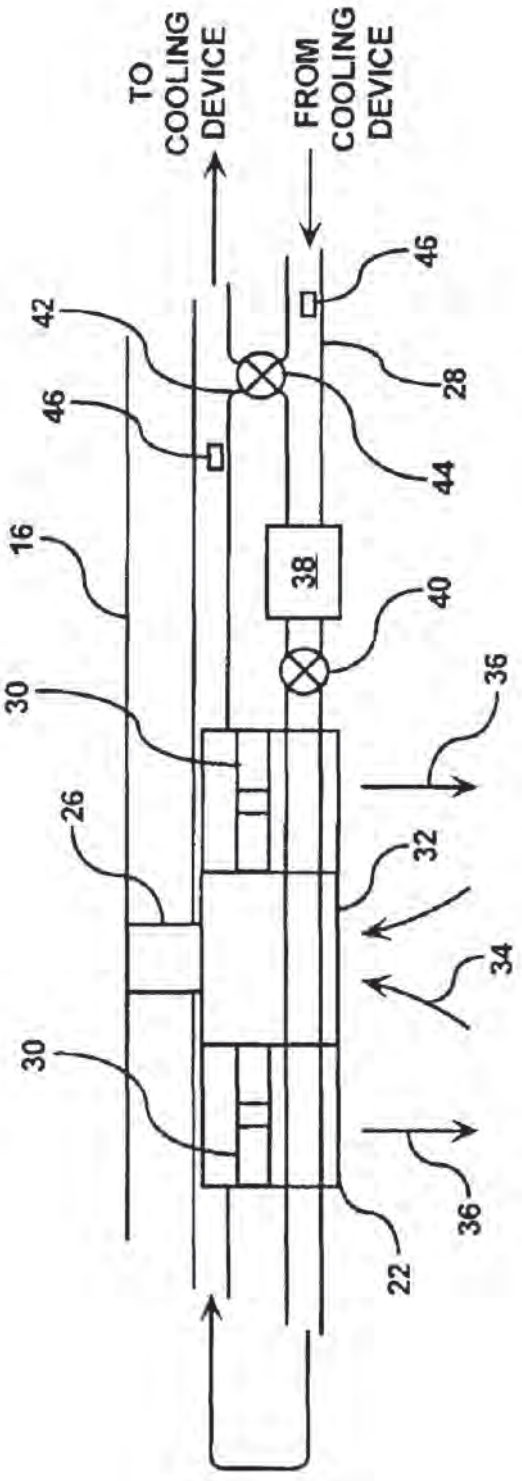

TO COOLING DEVICE
FROM COOLING DEVICE
46
42
28
46
44
16
38
40
30
36
26
32
34
30
36
22
48
12

FIG. 2

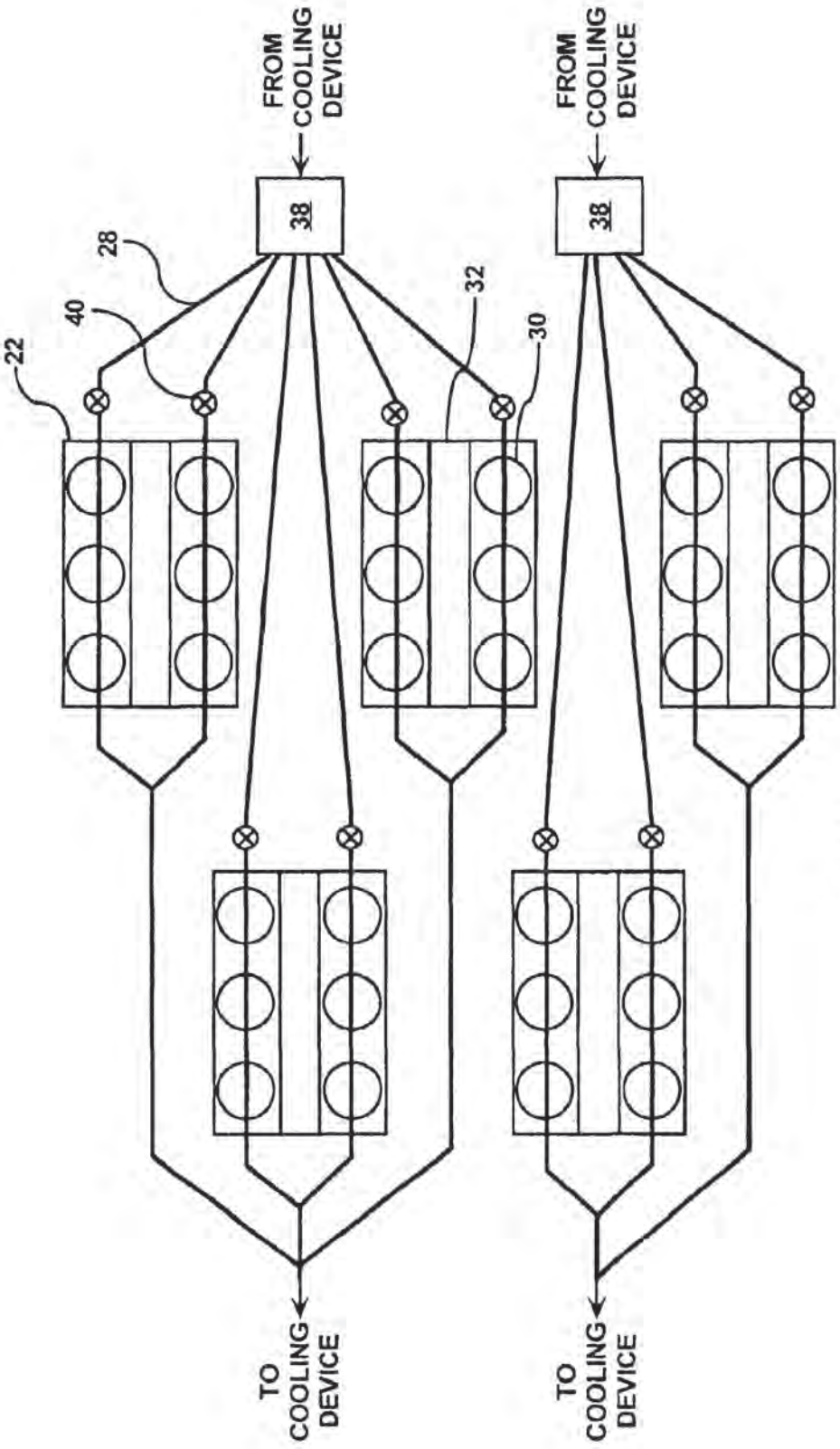

FROM COOLING DEVICE
FROM COOLING DEVICE
38
38
28
40
22
32
30
TO COOLING DEVICE
TO COOLING DEVICE

FIG. 3

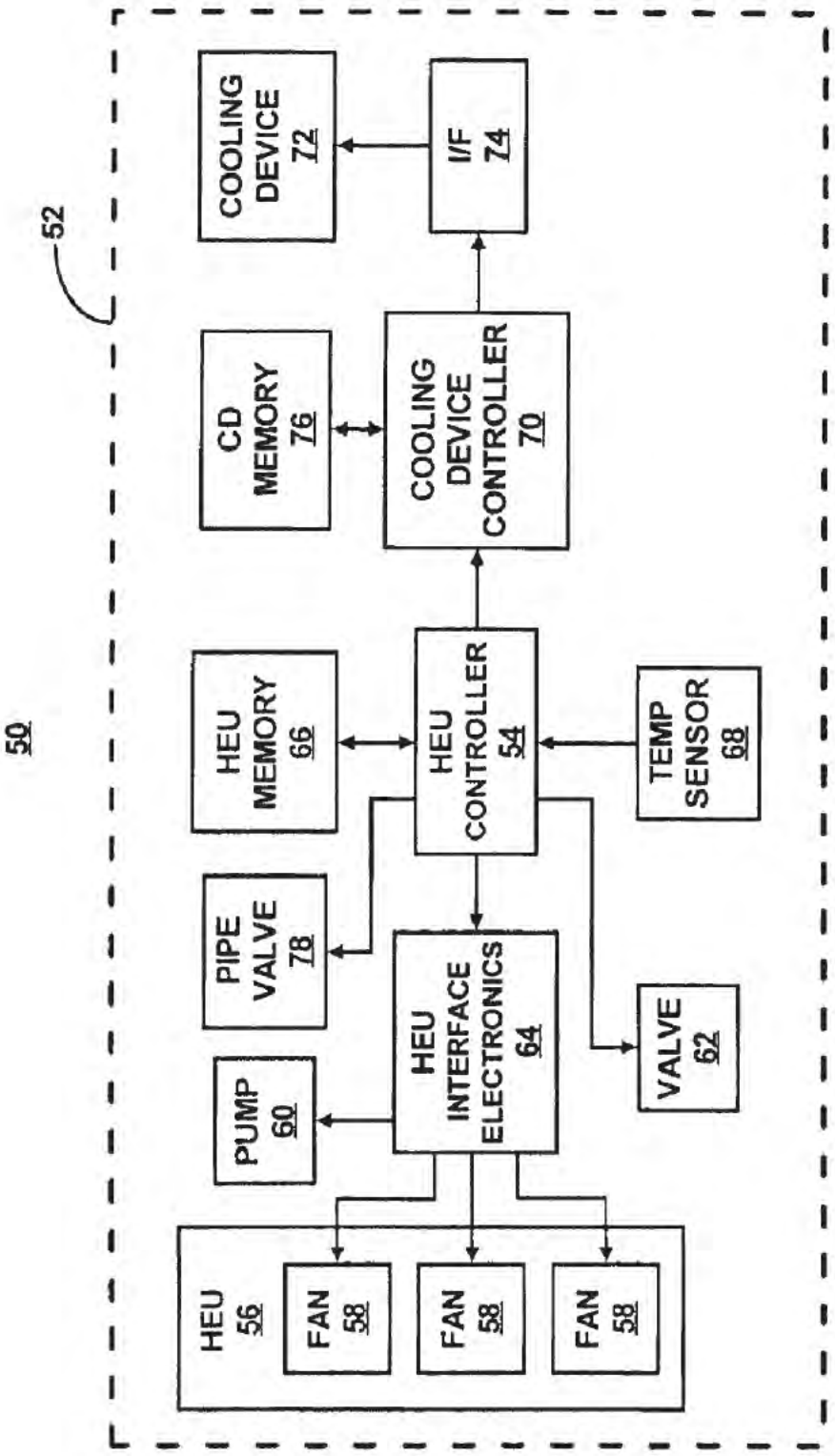

50
52
COOLING DEVICE 72
I/F 74
CD MEMORY 76
COOLING DEVICE CONTROLLER 70
HEU MEMORY 66
HEU CONTROLLER 54
TEMP SENSOR 68
PIPE VALVE 78
HEU INTERFACE ELECTRONICS 64
VALVE 62
PUMP 60
HEU 56
FAN 58
FAN 58
FAN 58

FIG. 4

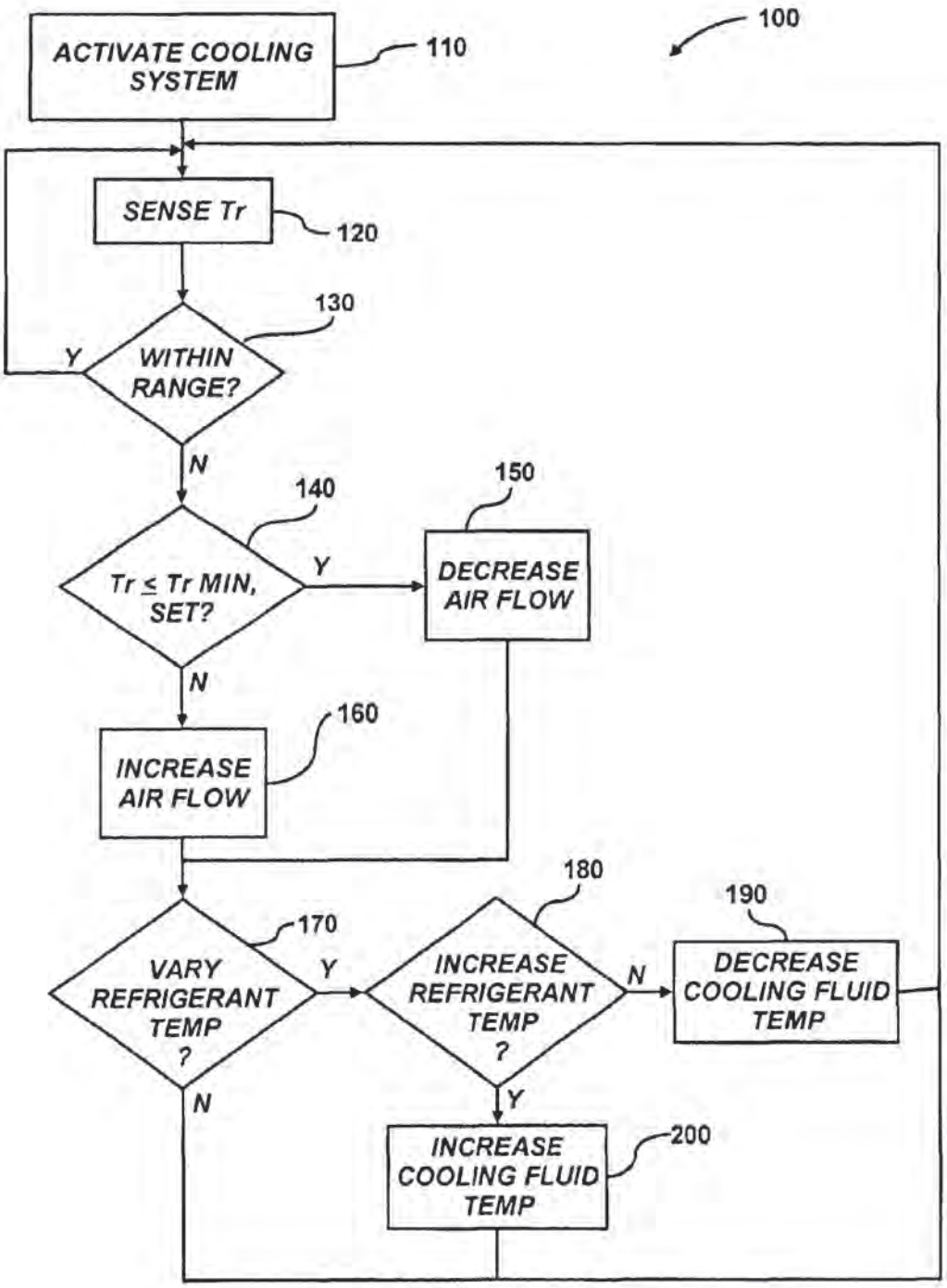

100
ACTIVATE COOLING SYSTEM
110
SENSE Tr
120
130
WITHIN RANGE?
Y
N
140
Tr ≤ Tr MIN, SET?
Y
150
DECREASE AIR FLOW
N
160
INCREASE AIR FLOW
170
VARY REFRIGERANT TEMP ?
Y
180
INCREASE REFRIGERANT TEMP ?
N
190
DECREASE COOLING FLUID TEMP
N
Y
200
INCREASE COOLING FLUID TEMP

FIG. 5

COOLING SYSTEM

CROSS-REFERENCES

This is a divisional of application Ser. No. 10/210,040, filed Aug. 2, 2002.

The present invention is related to pending U.S. application Ser. No. 09/970,707, filed Oct. 5, 2001, and entitled "SMART COOLING OF DATA CENTERS", by Patel et al., U.S. application Ser. No. 10/157,892 filed on May 31, 2002 entitled "CONTROLLED COOLING OF A DATA CENTER", by Patel et al., U.S. application Ser. No. 10/122,010, filed on Apr. 24, 2002, and entitled, "DATA CENTER ENERGY MANAGEMENT SYSTEM", by Friedrich et al., all of which are assigned to the assignee of the present invention and are incorporated by reference herein in their entireties.

FIELD OF THE INVENTION

This invention relates generally to cooling systems.

BACKGROUND OF THE INVENTION

A data center may be defined as a location, e.g., room, that houses computer systems arranged in a number of racks. A standard rack may be defined as an Electronics Industry Association (EIA) enclosure, 78 in. (2 meters) wide, 24 in. (0.61 meter) wide and 30 in. (0.76 meter) deep. Standard racks may be configured to house a number of computer systems, e.g., about forty (40) systems, with future configurations of racks being designed to accommodate up to eighty (80) systems. The computer systems typically include a number of components, e.g., one or more of printed circuit boards (PCBs), mass storage devices, power supplies, processors, micro-controllers, semi-conductor devices, and the like, that may dissipate relatively significant amounts of heat during the operation of the respective components. For example, a typical computer system comprising multiple microprocessors may dissipate approximately 250 W of power. Thus, a rack containing forty (40) computer systems of this-type may dissipate approximately 10 KW of power.

The power required to transfer the heat dissipated by the components in the racks to the cool air contained in the data center is generally equal to about 10 percent of the power needed to operate the components. However, the power required to remove the heat dissipated by a plurality of racks in a data center is generally equal to about 50 percent of the power needed to operate the components in the racks. The disparity in the amount of power required to dissipate the various heat loads between racks and data centers stems from, for example, the additional thermodynamic work needed in the data center to cool the air. In one respect, racks are typically cooled with fans that operate to move cooling fluid, e.g., air, cooling fluid, etc., across the heat dissipating components; whereas, data centers often implement reverse power cycles to cool heated return air. The additional work required to achieve the temperature reduction, in addition to the work associated with moving the cooling fluid in the data center and the condenser, often add up to the 50 percent power requirement. As such, the cooling of data centers presents problems in addition to those faced with the cooling of the racks.

Conventional data centers are typically cooled by operation of one or more air conditioning units. For example, compressors of air conditioning units typically require a minimum of about thirty (30) percent of the required operating energy to sufficiently cool the data centers. The other

components, e.g., condensers, air movers (fans), etc., typically require an additional twenty (20) percent of the required cooling capacity. As an example, a high density data center with 100 racks, each rack having a maximum power dissipation of 10 KW, generally requires 1 MW of cooling capacity. Air conditioning units with a capacity of 1 MW of heat removal generally requires a minimum of 300 KW input compressor power in addition to the power needed to drive the air moving devices, e.g., fans, blowers, etc. Conventional data center air conditioning units do not vary their cooling fluid output based on the distributed needs of the data center. Instead, these air conditioning units generally operate at or near a maximum compressor power even when the heat load is reduced inside the data center.

The substantially continuous operation of the air conditioning units is generally designed to operate according to a worst-case scenario. For example, air conditioning systems are typically designed around the maximum capacity and redundancies are utilized so that the data center may remain on-line on a substantially continual basis. However, the computer systems in the data center may only utilize around 30–50% of the maximum cooling capacity. In this respect, conventional cooling systems often attempt to cool components that may not be operating at a level which may cause their temperatures to exceed a predetermined temperature range. Consequently, conventional cooling systems often incur greater amounts of operating expenses than may be necessary to sufficiently cool the heat generating components contained in the racks of data centers.

SUMMARY OF THE INVENTION

According to one embodiment, the present invention pertains to a method for cooling a room configured to house a plurality of computer systems. In the method, there is provided a heat exchanger unit configured to receive air from the room and to deliver air to the room. The heat exchanger unit is supplied with cooling fluid that is operable to cool the received air in the heat exchanger unit. In addition, temperatures at one or more locations in the room are sensed and at least one of the temperature of the cooling fluid and the air delivery to the room is controlled in response to the sensed temperatures at the one or more locations.

According to another embodiment, the invention relates a system for cooling a room containing one or more computer systems. The system includes a heat exchanger unit configured to receive cooling fluid through a fluid line and to receive air, where the air may be cooled through heat transfer with the cooling fluid. The heat exchanger unit has at least one fan configured to cause air to flow out of the heat exchanger unit. The system also includes a heat exchanger controller operable to control a supply of the cooling fluid to the heat exchanger unit and operable to control the speed of the at least one fan. The system further includes a device for cooling the cooling fluid and a cooling device controller configured to operate the device for cooling to vary the temperature of the cooling fluid.

According to yet another embodiment, the present invention pertains to a system for cooling computer systems housed in one or more racks maintained in a room. The system includes means for cooling air including means for receiving cooling fluid. The system also includes means for delivering cooled air to the computer systems and means for measuring temperatures at one or more locations in the room. Additionally, the system includes means for controlling delivery of the cooled air in response to the

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measurements and means for controlling the temperature of the cooling fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

Features of the present invention will become apparent to those skilled in the art from the following description with reference to the figures, in which:

FIG. **1** shows a simplified schematic illustration of a room containing a cooling system in accordance with an embodiment of the invention;

FIG. **2** is an enlarged partly cross-sectional view of section A in FIG. **1**;

FIG. **3** is a schematic illustration taken along lines III—III of FIG. **1**;

FIG. **4** is an exemplary block diagram for a cooling system according to an embodiment of the invention; and

FIG. **5** shows a flow diagram of an operational mode according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

For simplicity and illustrative purposes, the present invention is described by referring mainly to an exemplary embodiment thereof. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent however, to one of ordinary skill in the art, that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention.

According to an embodiment of the present invention, a cooling system may include a heat exchanger unit (HEU) configured to receive cooling fluid (e.g., chilled water, R134a, ethylene glycol mixture, and the like). The HEU may be designed to cause air to exchange heat with the cooling fluid to thereby cool the air. The HEU may also be designed to deliver the cooled air to one or more computer systems. The cooling system may also include a cooling device operable to cool the cooling fluid. The cooling device may comprise one or more of known cooling systems (e.g., a closed loop refrigeration cycle configured to transfer heat with the cooling fluid). The cooling device may therefore include a second generally closed-loop system having refrigerant flowing through a refrigerant line and positioned to receive heat from the cooling fluid.

One or more controllers may be provided to operate the cooling system components. The one or more controllers may be configured to monitor environmental conditions within the room, and more particularly in areas around predetermined computer systems, and manipulate operation of the HEU and the cooling device according to the monitored environmental conditions. For example, the one or more controllers may control the temperature of the cooling fluid and/or the output of the HEU.

In one respect, by manipulating the output of the HEU and the temperature of the cooling fluid, the amount of energy required to cool the computer systems may be relatively low. Thus, according to the embodiment described above, instead of operating components of the cooling device, e.g., compressors, heat exchangers, fans, etc., at substantially 100 percent of the anticipated heat dissipation from the computer systems, those components may be operated according to the actual cooling needs. In addition, the computer systems and the racks in which they are housed may be positioned

throughout the room according to their anticipated heat loads, to additionally increase control over the energy required by the cooling system. Furthermore, as described in U.S. application Ser. No. 10/122,010, filed on Apr. 24, 2002, the loads may be distributed between various computer systems to further increase energy efficiency of air conditioning resources.

In another respect, the positioning of the racks may be determined through implementation of numerical modeling and metrology of the cooling fluid flow throughout the data center. In addition, the numerical modeling may be implemented to determine the volume flow rate and velocity of the cooling fluid flow through each of the HEU's.

A more detailed description of the above-described embodiment may be found in co-pending U.S. application Ser. No. 09/970,707, filed Oct. 5, 2001, which is assigned to the assignee of the present invention and is incorporated by reference herein in its entirety.

Referring first to FIG. **1**, there is illustrated a room **10**, e.g., a data center, housing a plurality of racks **12**, and a cooling system **20**. Also illustrated is a raised floor **14** that may be provided to enable placement of wires, tubes, and the like for delivery into and from the racks **12**.

The racks **12** may generally house a plurality of components (not shown), e.g., processors, micro-controllers, memories, semi-conductor devices, and the like. The components may be elements of a plurality of subsystems (not shown), e.g., computers, servers, etc. The subsystems and the components may be implemented to perform various electronic, e.g., computing, switching, routing, displaying, and the like, functions. In the performance of these electronic functions, the components, and therefore the subsystems, may dissipate relatively large amounts of heat. Because the racks **12** have been generally known to include upwards of forty (40) or more subsystems, they may require substantially large amounts of cooling fluid to maintain the subsystems and the components generally within a predetermined operating temperature range. According to an embodiment of the invention, by substantially controlling the amount of cooling air delivered to the components and the subsystems located in the racks **12** based upon their respective heat loads, the power consumed by the cooling system **20** to cool and supply the cooling fluid may also be controlled.

The cooling system **20** is illustrated as including a plurality of HEU's **22** and a cooling device **24**. The HEU's **22** may be supported from a ceiling **16** of the room **10** by one or more supports **26**. The HEU's **22** may comprise any reasonably suitable air conditioning unit designed to receive air and to deliver the received air, e.g., the DATACOOL environmental control system manufactured and distributed by Liebert of Irvine, Calif. As can be seen in FIG. **1**, the HEU's **22** are positioned to receive air that may become heated by virtue of the heat dissipated by, for example, the computer systems located in the racks **12**. Although an HEU **22** is illustrated as positioned over a rack **12**, it should be understood that the HEU's **22** may be positioned at various other locations. For example a plurality of HEU's **22** may be positioned to cool a single rack. Determinations of HEU **22** placement within the room **10** may be predicated upon techniques designed to optimize cooling performance and/or energy efficiency.

The HEU's **22** may be positioned to generally supply the racks **12** with cooling air. More particularly, the HEU's **22** may be positioned to supply cooling air to the racks **12** in accordance with their heat dissipation [illegible]

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computer systems that undergo higher loads are known to generate greater amounts of heat as compared to computer systems that undergo lower or no loads. Thus, the HEU's **22** may be positioned and operated to supply those computer systems (and racks **12**) that generate greater amounts of heat with greater mass flow rates of cooling air and/or relatively lower temperature air. In addition, those computer systems (and racks **12**) that generate little or no heat, may likewise, receive little or no cooling air and/or relatively higher temperature air. In this respect, the amount of energy required to operate the HEU's **22** specifically, and the cooling system **20** as a whole, may be substantially optimized according to the demands of the computer systems.

Alternatively, or additionally to the above, because usage of the computer systems contained in the racks **12** may vary at different times of the day, instead of varying the position of the HEU's **22**, the load placed on the computer systems may be varied. For instance, as described in co-pending U.S. application Ser. No. 10/122,010, the work load on some of the computer systems may be performed by other computer systems to substantially maximize energy efficiency of the cooling system. In this regard, the load may be transferred, for example, to one location in the room **10** if it is determined that such a load transfer is more energy efficient than under normal operating conditions. Moreover, the load transfer may occur at different times of the day and as load requirements vary.

The cooling device **24** may comprise any reasonably suitable type of cooling device designed to adequately cool the cooling fluid. In addition, the cooling device **24** may include the capability of varying the temperature of the cooling fluid. Some suitable cooling devices may include those that implement air conditioners, heat exchangers, heat pumps, variable capacity chillers, evaporative cooling systems, and the like. For example, the cooling device **24** may comprise a closed-loop refrigeration cycle apparatus having a heat transfer section where the heat from the cooling fluid in a fluid line **28** may be transferred to refrigerant contained in the closed-loop refrigeration cycle apparatus.

Although the cooling device **24** is illustrated as being located outside of the room **10**, it should be understood that the cooling device **24** may be positioned within the room **24** without deviating from the scope of the present invention.

The cooling fluid may be configured to flow through the HEU's **22** and return to the cooling device **24** via fluid lines **28**. As seen in FIG. **1**, the fluid line **28** generally forms a closed loop system in which the cooling fluid may become heated in the HEU's **22** and cooled in the cooling device **24**.

Although one room **10** is illustrated in FIG. **1**, it should be understood that the room **10** may comprise more than one room and that the cooling system **20** may be configured to cool a plurality of rooms.

With reference now to FIG. **2**, there is illustrated an enlarged partly cross-sectional view of section A in FIG. **1**. As seen in FIG. **2**, the HEU **22** generally comprises, among other things, a plurality of fans **30** and an opening **32**. The fans **30** are designed to cause air from the room **10** to flow into the opening **32**, as indicated by arrows **34**. The fans **30** are also configured to cause the air to flow back out into the room **10**, in the manner indicated by arrows **36**. It should be understood that the HEU **22** may include additional components and that some of the components described may be removed and/or modified without departing from the scope of the invention.

The fluid line **28** is situated to run through the HEU **22** below the fans **30** and in the direction of air flow from the HEU **22** to the room **10**. In this respect, as the air flows by the fluid line **28**, heat may be transferred from the air to the cooling fluid contained in the fluid line **28**. Consequently, the air flowing out of the HEU **22** may be at a lower temperature relative to the air entering the HEU **22**.

A pump **38** may be provided along the fluid line **28** at a location generally upstream of the HEU **22**. The pump **38** may be designed to apply sufficient pressure to the cooling fluid entering the HEU **22** to enable the cooling fluid to flow at a predetermined rate through the HEU **22**. In this respect, the pump **38** may comprise any pump capable of performing the above-described operations in a reasonably suitable manner. The pump **38** may be configured to supply cooling fluid to a plurality of HEU's **22** and to control the pressure of the cooling fluid flowing through one or more of the HEU's **22**. A valve **40** is illustrated between the pump **38** and the HEU **22** along the fluid line **28**. The valve **40** may be an electronically controllable valve capable of varying the flow of cooling fluid through the fluid line **28**, as well as substantially stopping the flow of the cooling fluid. As a result, the volume flow rate of the cooling fluid through the fluid line **28** extending through the HEU **22** may be manipulated at predetermined levels such that the temperature of the air flowing out of the HEU **22** may be substantially optimized.

Although the pump **38** and the valve **40** are illustrated as separate components, it should be understood that their respective functions may be performed by a single component, e.g., the pump **38**. In this example, the pump **38** may be configured as a variable speed pump configured to vary the flow of cooling fluid through the HEU **22**.

A pipe **42** may be located along the fluid line **28** at a location downstream of the HEU **22**. The pipe **42** may enable cooling fluid that has passed through the HEU **22** to be introduced into cooling fluid entering into the HEU **22**. A pipe valve **44** may be positioned along the pipe **42** to substantially control the amount of this cooling fluid introduced into the cooling fluid entering into the HEU **22**. The pipe valve **44** may be any reasonably suitable valve (e.g., a three-way valve) capable of controlling the cooling fluid flow through the pipe **42**.

In this respect, the temperature of the cooling fluid may thus be further controlled. By way of example, the temperature of the cooling fluid may be increased prior to its introduction into an HEU **22** in a multi-HEU system (see e.g., FIG. **3**). In this type of configuration, when one rack **12** is dissipating a greater amount of heat relative to another rack **12**, the temperature of cooling air flow supplied to each of these racks may differ from one another. That is, the rack **12** dissipating the greater amount of heat may receive air flow from a first HEU **22** that is at a lower temperature compared to the rack that is dissipating a lesser amount of heat. Consequently, the temperature of the cooling fluid introduced into that first HEU may be at a lower temperature than the cooling fluid introduced into a second HEU.

Temperature sensors **46** may be located in a supply portion and a return portion of the fluid line **28** such that a determination may be made as to changes in the cooling fluid temperature prior to and following flow through the HEU **22**. This information may be implemented to determine the amount of return cooling fluid to be introduced into the supply portion of the fluid line **28**.

A temperature sensor **48** e.g., a thermocouple or the like, is illustrated on the rack **12**. A single temperature sensor **48** is depicted in FIG. **2** for purposes of simplicity, it should, however, be understood that a plurality of temperature sensors **48** may be positioned at various locations [illegible]

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12 as well as other areas of the room **12**. The temperature sensor **48** may supply temperature readings to a controller (not shown) configured to operate the HEU **22**, the pump **38**, the valve **40**, and the pipe valve **44**. In addition, the temperature readings may also be supplied to a controller (not shown) configured to operate the cooling device **24**. The manner of information transmittal between the temperature sensor **48** and the controllers may comprise any reasonably suitable arrangement, e.g., wired or wireless connection.

In place of, or in addition to, the temperature sensor **48**, a mobile device (not shown) designed to gather or measure at least one local environmental condition (e.g., temperature, air flow, humidity, etc.) in the room **10** may be implemented. By way of example, a suitable mobile device may comprise the environmental condition detecting device described in co-pending U.S. application Ser. No. 10/157,892, filed on May 31, 2002 entitled "CONTROLLED COOLING OF A DATA CENTER", by Patel et al., which is assigned to the assignee of the present invention and incorporated by reference herein in its entirety. Information gathered by the mobile device may be transmitted to the controller, which may vary operation of the cooling system **20** in response to the information.

Alternatively, or in addition to, the above-described environmental condition sensing devices, the amount of heat generated by the computer systems contained in the racks **12**, and the resulting necessary cooling requirements, may be anticipated according to the amount of load placed on the computer systems. A suitable method of implementing anticipated sensing is described in co-pending U.S. application Ser. No. 09/970,707, which is assigned to the assignee of the present invention and incorporated by reference herein in its entirety.

Referring now to FIG. **3**, there is shown a schematic illustration taken along lines III—III of FIG. **1**. FIG. **3** illustrates a plurality of HEU's **22** and a plurality of fluid lines **28** emanating from a pair of pumps **38**. The illustration also shows that the HEU's **22** include rows of fans **30** located adjacent to the openings **32**. Situated beneath each of the fans **30** are fluid lines **28**. In addition, located generally upstream of the HEU's **22** are respective valves **40**, which may comprise three-way valves. As can be seen in FIG. **3**, the pumps **38** may control the supply of cooling fluid through a plurality of HEU's **22**. In addition, it may be seen that the valves **40** generally enable control of cooling fluid flow through respective fluid lines **28**.

In this respect, the temperature of the air flowing out of the HEU's **22**, and more specifically, out of each side of the HEU's **22** may be controlled in substantially independent manners (e.g., by operation a three-way valves (not shown)). In one regard, the flow of cooling fluid through certain HEU's **22** may be restricted or substantially halted, for instance, in situations where the computer systems for which an HEU **22** is configured to cool are in idle states. It should be understood that the configuration of HEU's **22**, pumps **38**, fluid lines **28**, and valves **40** depicted in FIG. **3** is but one manner of a variety of different obtainable configurations. It should also be understood that the specific configuration for any given room may depend upon a multitude of factors, e.g., cooling needs, room configuration, cooling device type, etc. In addition, the fluid lines **28** may be positioned above the fans **30** such that air may substantially be cooled prior to flowing into the fans **30** without deviating from the scope of the present invention.

FIG. **4** is an exemplary block diagram **50** for a cooling system **52** according to an embodiment of the invention. It should be understood that the following description of the block diagram **50** is but one manner of a variety of different manners in which such a cooling system **52** may be operated. In addition, it should be understood that the cooling system **52** may include additional components and that some of the components described may be removed and/or modified without departing from the scope of the invention.

The cooling system **52** includes an HEU controller **54** configured to control the operations of the HEU **56**. The HEU controller **54** may comprise a microprocessor, a micro-controller, an application specific integrated circuit (ASIC), and the like. The HEU controller **54** may, for example, control the speed of the fans **58**, the operation of the pump **60**, the valve **62**, and the pipe valve **78**. Interface electronics **64** may be provided to act as a control interface between the HEU controller **54** and the HEU **56**, pump **60**, and valve **62**. Alternatively, a control interface my be omitted between the HEU controller **54** and the above-described components as seen with respect to the connection between the HEU controller **54** and, for example, the pipe valve **78**. The HEU controller **54** may also be interfaced with a temperature sensor **68**, e.g., one or more of the temperature sensors described hereinabove with respect to FIG. **2**.

The HEU controller **54** may be interfaced with an HEU memory **66** configured to provide storage of a computer software that provides the functionality of the HEU controller **54**, e.g., the speed of the fans, pump operation, etc. The HEU memory **66** may be implemented as a combination of volatile and non-volatile memory, such as dynamic random access memory (DRAM), EEPROM, flash memory, and the like. The HEU memory **66** may also be configured to provide a storage for containing data and/or information pertaining to the manner in which HEU controller **54** may operate the fans **58**, the pump **60**, the valve **62**, and the pipe valve **78**. In one respect, the manner of operation of the above-described components may be based according to temperature measurements by the temperature sensor **68**.

The HEU controller **54** may be further interfaced with a cooling device controller **70**. The interface may be effectuated via a wired protocol, such as IEEE 802.3, etc., wireless protocols, such as IEEE 801.11b, wireless serial connection, Bluetooth, etc., or combinations thereof.

The cooling device controller **70** may be configured to control the operations of the cooling device **72**. The cooling device controller **70** may comprise a microprocessor, a micro-controller, an application specific integrated circuit (ASIC), and the like. The cooling device controller **70** is generally configured to manipulate the temperature of the cooling fluid by controlling the operation of the cooling device **72**. In this regard, the cooling device **72** may comprise a variable speed compressor, a heat exchanger, a chilled water heat exchanger, a centrifugal chiller, and the like. More particularly, the cooling device controller **70** may be designed to vary the operation of one or more of the above-recited components to vary the amount of heat transfer on the refrigerant contained in the refrigeration loop of the cooling device **72** to thereby vary the cooling fluid temperature.

Interface electronics (I/F) **74** may be provided to act as an interface between the cooling device controller **70** and the components for operating the cooling device **72**, e.g., the supply of voltage to vary the speed of the compressor, control of the heat exchanger (centrifugal chiller) capacity, etc.

The cooling device controller **70** may also be interfaced with a cooling device (CD) memory **76** configured to

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provide storage of a computer software that provides the functionality of the cooling device **72**, e.g., compressor, heat exchanger, and the like, and may be executed by the cooling device controller **70**. The CD memory **76** may be implemented as a combination of volatile and non-volatile memory, such as DRAM, EEPROM, flash memory, and the like. The CD memory **76** may also be configured to provide a storage for containing data/information pertaining to the manner in which the compressor (heat exchanger, chiller) may be manipulated in response to, for example, variations in the temperature of the cooling fluid and/or air in the room.

In one respect, the capacity (e.g., the amount of work exerted on the cooling fluid) of the compressor (heat exchanger, chiller, etc.) may be modified to thereby control the temperature and of the cooling fluid. The compressor (heat exchanger, chiller, etc.) may thus be controlled to either increase or decrease the mass flow rate of the refrigerant flowing therethrough. Consequently, when the temperature in the room **10** is below a predetermined range, the capacity of the (heat exchanger, chiller, etc.) may be reduced to substantially reduce the amount of work, thus the amount of energy exerted on the refrigerant. This may lead to a significant reduction in the costs associated with operating the cooling system **52** as compared with conventional cooling systems.

Because the specific type of compressor (heat exchanger, chiller, etc.) to be employed with embodiments of the invention may vary according to individual needs, the invention is not limited to any specific type of compressor (heat exchanger, chiller, etc.). Instead, any reasonably suitable type of compressor (heat exchanger, chiller, etc.) capable of accomplishing certain aspects of the invention may be employed with the embodiments of the invention. The choice of compressor (heat exchanger, chiller, etc.) may therefore depend upon a plurality of factors, e.g., cooling requirements, costs, operating expenses, etc.

By way of example, if there is a detected or anticipated change in the temperature of a rack, e.g., rack **12**, areas surrounding the rack, etc., the HEU controller **54** may operate to manipulate the corresponding HEU **56** and/or fan(s) **58** to compensate, e.g., change the volume flow rate, velocity, and other characteristic of the air flow, for the change in temperature. In addition, or as an alternative to the above, the cooling device controller **70** may operate to cause the cooling device **72** to lower the refrigerant temperature. In this respect, each of the racks **12** and/or portions thereof may generally receive substantially only the amount of cooling air necessary to maintain the temperature of the racks **12** within a predetermined temperature range. In addition, the refrigerant, and therefore the cooling fluid, temperature may also be controlled as needed to substantially optimize cooling of the racks **12**. By controlling the cooling air flow in the above-described manner, the cooling system **52** may be operated at substantially optimized levels, thereby decreasing the amount of energy and thus the operating costs required to cool the computer systems in the racks **12**.

Moreover, the cooling device controller **70** may operate the compressor (heat exchanger, chiller, etc.) in a manner to vary the cooling fluid temperature in response to various degrees of detected increases/decreases in the operation of the HEU **56**. More particularly, a look up table (not shown) may be stored in the CD memory **76**. The look up table may include information pertaining to the level of compressor speed (heat exchanger capacity, etc.) increase necessary for a detected increase in the operation of the HEU **56**. In this respect, the compressor speed (heat exchanger capacity, etc.) may be varied substantially incrementally in response to detected changes in the operation of the HEU **56**.

FIG. **5** shows a flow diagram of an operational mode **100** according to an embodiment of the invention. It should be understood that the operational mode **100** may include additional operations and that some of the operations may be removed and/or modified without departing from the scope of the invention. The following description of the operational mode **100** is made with reference to the block diagram **50** illustrated in FIG. **4**, and thus makes reference to the elements cited therein.

The operations illustrated in the operational mode **100** may be contained as a utility, program, or a subprogram, in any desired computer accessible medium. In addition, the operational mode **100** may be embodied by a computer program, which can exist in a variety of forms both active and inactive. For example, they can exist as software program(s) comprised of program instructions in source code, object code, executable code or other formats. Any of the above can be embodied on a computer readable medium, which include storage devices and signals, in compressed or uncompressed form.

Exemplary computer readable storage devices include conventional computer system RAM, ROM, EPROM, EEPROM, and magnetic or optical disks or tapes. Exemplary computer readable signals, whether modulated using a carrier or not, are signals that a computer system hosting or running the computer program can be configured to access, including signals downloaded through the Internet or other networks. Concrete examples of the foregoing include distribution of the programs on a CD ROM or via Internet download. In a sense, the Internet itself, as an abstract entity, is a computer readable medium. The same is true of computer networks in general. It is therefore to be understood that those functions enumerated below may be performed by any electronic device capable of executing the above-described functions.

In the operational mode **100**, the cooling system **52** is activated at step **110**. At step **120**, the temperature of one or more racks (Tr) is sensed by temperature sensors, e.g., one or more temperature sensors **68**. The temperature sensors may comprise one or more of the above-described temperature sensors, e.g., thermocouple, mobile environmental condition sensing device, etc. The Tr's generally correspond to the heat load of the heat dissipating components and therefore the computer systems contained in the racks, e.g., rack **12**. Therefore, the Tr's may be based upon the temperatures of specific heat dissipating components and subsystems. In addition, the Tr's may be based upon the temperatures in the general vicinity of the racks and/or sections of the racks. Thus, those skilled in the art will understand that certain embodiments of the present invention may be employed with temperature sensors located at various positions throughout the room, e.g., room **10**. Moreover, use of the term "rack" herein generally refers to racks for supporting computer systems and additionally to sections of the racks as well as areas around the racks. Therefore, the use of the term "rack" throughout the present disclosure is not meant to limit certain aspects thereof to entire racks, but instead, is relied upon to simplify the description of certain embodiments of the present invention.

As an alternative to the temperature sensor **68**, the Tr's may be anticipated in the manner described hereinabove and in co-pending U.S. patent application Ser. No. 09/970,707.

At step **130**, it is determined whether each of the Tr's is within a predetermined range of operating temperatures.

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e.g., between a maximum set point temperature (Tmax,set) and a minimum set point temperature (Tmin,set). In general, the range of temperatures Tmin,set and Tmax,set pertains to threshold temperatures to determine whether to increase or decrease the flow of cooling air delivered to the racks. This range of operating temperatures may be set according to a plurality of factors. These factors may include, for example, the operating temperatures set forth by the manufacturers of the subsystems and components located in the racks, through testing to determine the optimal operating temperatures, etc. In addition, the predetermined range of operating temperatures may vary from one subsystem to another.

For those racks having Tr's that are within the predetermined range, their temperatures are sensed again at step **120**. For those racks determined to have heat loads that do not fall within the predetermined temperature range, i.e., fall outside of Tmin,set and Tmax,set, the HEU controller **54** may determine whether those racks have temperatures that are below the Tmin,set at step **140**.

The air flow supplied by the HEU **56**, and more particularly the fans **58**, configured to supply cooling air flow to the racks having Tr's below or equal to the Tmin,set, may be decreased at step **150**. In addition, and/or alternatively, the temperature of the cooling fluid supplied through the HEU's **56** may be increased to thereby increase the temperature of the air supplied to these racks. As described hereinabove, this may be accomplished by decreasing the work placed on the refrigerant by the cooling device **72** and/or by opening the bypass valve **62**. Additionally, the temperature of the air flowing from the HEU **56** may also be increased by causing the valve **78** to enable a lower volume flow rate of cooling fluid to flow therethrough.

The air flow supplied by the HEU **56** configured to supply cooling air flow to the racks having Tr's above the Tmin,set, and thus above the Tmax,set, may be increased at step **160**. In this regard, the HEU controller **54** may increase power to the fans **58** to enable greater air flow to the racks. In addition, and/or alternatively, the HEU controller **54** may increase the flow of cooling fluid through the HEU **56** via operation of the pump **60** and/or the valve **78**.

By virtue of certain embodiments of the invention, racks having various Tr's may be supplied with air flow having various characteristics, e.g., temperature, velocity, direction, and the like. That is, for example, in a system comprising a plurality of HEU's **56**, air flow may be supplied to racks having higher Tr's by certain HEU's **56** substantially simultaneously with air flow supplied to racks having relatively lower Tr's by other HEU's **56** where each of the racks receives different levels of air flow. Additionally, the temperature of the cooling fluid supplied through the HEU's **56** delivering air flow to racks having higher Tr's may be relatively lower than the temperature of the cooling fluid supplied through the HEU's **56** delivering air flow to racks having lower Tr's. It should thus be appreciated that steps **150** and **160** may be respectively and substantially simultaneously performed by various HEU's **56**.

According to an embodiment of the invention, the decrease in volume flow rate and/or velocity of the air flow at step **150** and the increase in volume and/or velocity of the air flow at step **160** may be accomplished by incrementally varying the air flow from the HEU **56**. For example, the volume flow rate and/or velocity of the air flow from the HEU **56** may be varied by a predetermined amount during a first iteration. The Tr may be measured at a predetermined time following the variation and steps **130–160** may be repeated. By repeating this process a number of times, the temperature of the rack may be substantially brought within the predetermined range.

At step **170**, the cooling device controller **70** may determine whether to vary the cooling fluid temperature, e.g., increase the compressor speed (heat exchanger capacity, etc.). The cooling fluid temperature may be decreased in response to, for example, actual and/or detected increases in Tr. In the alternative, the decrease in cooling fluid temperature may be predicated upon the amount of work performed by the HEU **56**. More particularly, as the work performed by the HEU **56** increases, thereby signaling an increase in the Tr, the cooling device controller **70** may cause the cooling device **72** to decrease the refrigerant temperature. In addition, when a plurality of HEU's **56** are implemented to cool one or more racks, the cooling device controller **70** may determine whether the total amount of decreases in the volume flow rates of the cooling air exceeds the total amount of increases in the volume flow rates flow of the cooling air. At step **180**, the cooling device controller **70** may determine whether to decrease the cooling fluid temperature.

At step **190**, the cooling device controller **70** may cause the cooling fluid temperature to be decreased in response to a determination to do so at step **180**. Alternatively, the cooling device controller **70** may cause the cooling fluid temperature to be increased at step **200** in response to a determination to do so at step **180**. As described hereinabove, the cooling device controller **70** may operate to vary the temperature of the cooling fluid by varying the speed of the compressor, capacity of the heat exchanger, and the like.

It should be understood that steps **150**, **160**, and **190** or **200** may be performed substantially simultaneously. More particularly, on a zonal level, temperature readings determined at step **120** for various racks may be implemented in varying the delivery of cooling air to the various racks. Additionally, on a global level, the temperature of the cooling fluid may be varied according to the changes in the cooling requirements of the racks. For example, when the temperature of a rack exceeds a predetermined threshold range, the HEU(s) **56** supplying cooling air flow to that rack may increase the air flow to that rack. Substantially concurrently, the temperature of the cooling fluid may be decreased by an amount relative to the increased rack temperature.

Following steps **190** or **200**, the Tr's are sensed again at step **120**. In addition, the steps following step **120** may be repeated for an indefinite period of time and may form a closed-loop pattern.

In accordance with embodiments of the present invention, the cooling requirements of a room configured to house computer systems may be analyzed to substantially optimize the layout of the racks within the room. In one respect, the substantial optimization of the rack layout in the room may enable the cooling system of the data center to operate at generally lower energy and greater efficiency levels by virtue of the reduced workload placed on the components of the cooling systems, e.g., compressors, HEU's, etc. In addition, the cooling requirements may be analyzed to optimize the workload of the computer systems as described above. In this regard, the actual or anticipated temperatures may be stored in a look-up table and used as references in optimizing the room layout and/or workload distribution. The cooling requirements within the room may be analyzed by operation of any reasonably suitable commercially available computational fluid dynamics [illegible]

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FLOVENT, a 3-D modeling software capable of predicting temperature variations based upon fluid flow analyses.

By virtue of the numerical modeling, various cooling devices as well as the HEU's described hereinabove may be positioned throughout the room to substantially control the manner in which the racks receive the cooling fluid.

In addition, the cooling devices may also be positioned to substantially maximize and optimize their performances, e.g., to prevent one or more of the cooling devices from operating at substantially excessive levels.

In determining the cooling air distribution requirement within the room, each of the racks may be assigned a heat load which may correspond to a maximum heat load predicted for that rack, e.g., through anticipated power draw. For example, a rack containing 40 subsystems, e.g., computers, may have a maximum heat load of 10 KW and a rack containing 20 subsystems may have a maximum heat load of 5 KW. By implementing the CFD in this manner, for example in a room containing 100 racks, four cooling devices, and a plurality of HEU's, racks having a potential for relatively larger heat loads may be relatively separately located throughout the data center. In one respect, therefore, the cooling devices and the HEU's within the room may be operated at substantially less than maximum power levels while the racks may receive sufficient amounts of cooling fluid. More specifically, the power required to operate the cooling devices and the HEU's may be regulated to efficiently supply cooling fluid to the racks by providing substantially only that amount of cooling fluid necessary to maintain the racks within nominal operating temperatures.

Additionally, a CFD tool may be implemented substantially simultaneously with the cooling system. More specifically, the CFD tool may be utilized to substantially continuously vary the operation of the cooling system to operate according to the heat loads generated in the racks. In this regard, the anticipated or actual heat loads (e.g., based upon the power draw of the components) on the racks may be inputted into the CFD tool, along with one or more of the following properties: velocity of the cooling fluid flowing through various sections of the room and the distribution of temperature and pressure of the cooling fluid in the data center, to determine an optimal manner in which, for example, the HEU's may be operated. The velocity of the air flow as well as other atmospheric conditions at various locations within the room may be sensed by a temperature sensor. The sensed conditions may be transmitted or otherwise relayed to the CFD tool to enable the tool to perform the necessary calculations.

In this regard, the CFD tool may be implemented to produce a numerical model of the room to thus determine an optimized cooling distribution within the room. A correlation of one or more of the following properties: velocity of the cooling fluid flowing through various sections of the room, distribution of temperature and pressure of the cooling fluid in the room, and the power draw into the racks, may be created based on the numerical modeling. The correlation may be used to infer thermal conditions throughout the room when only a minimum number of sensors are available during operation of the cooling system. In addition, the correlation may substantially reduce the amount of time required for the CFD tool to perform the computing operations.

By virtue of certain embodiments of the present invention, one of ordinary skill in the art will readily recognize that the amount of energy, and thus the costs associated with cooling the racks located within a room may be substantially reduced. In one respect, by operating the cooling system to supply cooling fluid substantially only as needed by the racks, the cooling system may be operated at a relatively more efficient manner in comparison with conventional cooling systems.

What has been described and illustrated herein is a preferred embodiment of the invention along with some of its variations. The terms, descriptions and figures used herein are set forth by way of illustration only and are not meant as limitations. Those skilled in the art will recognize that many variations are possible within the spirit and scope of the invention, which is intended to be defined by the following claims—and their equivalents—in which all terms are meant in their broadest reasonable sense unless otherwise indicated.

What is claimed is:

1. A method for cooling a room configured to house a plurality of computer systems, said method comprising:

providing a plurality of heat exchanger units configured to receive air from said room and to deliver air to said room;

supplying said plurality of heat exchanger units with cooling fluid from an air conditioning unit;

cooling said received air through heat exchange with the cooling fluid in the plurality of heat exchanger units;

sensing temperatures at one or more locations in said room;

controlling at least one of the temperature of said cooling fluid and said air delivery by said plurality of heat exchanger units to said room in response to said sensed temperatures at said one or more locations; and

wherein the step of controlling said air delivery by said plurality of heat exchanger units comprises individually manipulating a mass flow rate of the cooling fluid supplied to each of the plurality of heat exchanger units.

2. The method according to claim **1**, wherein said step of controlling at least one of a temperature of said cooling fluid and said air delivery to said room comprises varying an output of said air conditioning unit to control the temperature of said cooling fluid.

3. The method according to claim **1**, further comprising: determining whether the sensed temperatures at one or more locations in said room are within a predetermined range.

4. The method according to claim **3**, further comprising: varying the cooling fluid temperature in response to the sensed temperatures at one or more locations in said room being outside of said predetermined range.

5. The method according to claim **4**, further comprising: increasing said cooling fluid temperature in response to a sum of the sensed temperatures at one or more locations being below said predetermined range.

6. The method according to claim **4**, further comprising: decreasing said cooling fluid temperature in response to a sum of the sensed temperatures at one or more locations being above said predetermined range.

7. The method according to claim **1**, wherein the step of manipulating a mass flow rate of the cooling fluid supplied to each of the plurality of heat exchanger units further comprises metering the flow of cooling fluid through each of said plurality of heat exchanger units with a plurality of valves positioned along respective cooling fluid lines configured to channel cooling fluid from the air conditioning unit to the plurality of heat exchanger units.

8. The method according to claim **1**, wherein the step of manipulating a mass flow rate of the cooling fluid supplied

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to each of the plurality of heat exchanger units further comprises metering the flow of cooling fluid through said plurality of heat exchanger units with a plurality of pumps positioned along respective cooling fluid lines configured to channel cooling fluid from the air conditioning unit to the plurality of heat exchanger units.

9. The method according to claim **1**, further comprising:

manipulating a mass flow rate of the cooling fluid supplied to the plurality of heat exchanger units in substantially independent manners with respect to each of the plurality of heat exchanger units.

10. A system for cooling a room containing one or more computer systems, said one or more computer systems being housed in a plurality of racks, said system comprising:

a plurality of heat exchanger units configured to receive cooling fluid through a cooling fluid line from an air conditioning unit for cooling the cooling fluid, said plurality of heat exchanger units being further configured to receive air through openings in the plurality of heat exchanger units, wherein said air is cooled through heat transfer with said cooling fluid in the plurality of heat exchanger units;

said plurality of heat exchanger units having at least one fan configured to cause air to flow into and flow out of the heat exchanger unit;

a heat exchanger controller operable to control a supply of said cooling fluid to said plurality of heat exchanger units and operable to control the speed of the at least one fan;

one or more temperature sensors for sensing temperatures at one or more locations in the room;

an air conditioning unit controller configured to operate the air conditioning unit to vary the temperature of said cooling fluid delivered to the one or more locations in the room; and

a plurality of pumps configured to control cooling fluid delivery to respective ones of said plurality of heat exchanger units, wherein said heat exchanger controller is operable to control said plurality of pumps to thereby individually control the mass flow rate of cooling fluid delivered into each of the respective heat exchanger units.

11. The system according to claim **10**, further comprising one or more temperature sensors, wherein said heat exchanger controller is configured to receive environmental condition information from said one or more temperature sensors.

12. The system according to claim **10**, wherein said cooling device comprises at least one of a variable capacity compressor, a heat exchanger, a chiller, and a cooling device controller configured to control said at least one of said variable capacity compressor, said heat exchanger, and said chiller.

13. The system according to claim **10**, wherein said heat exchanger controller is operable to control said plurality of pumps to supply cooling fluid to the plurality of heat exchanger units in substantially independent manners with respect to each of the plurality of heat exchanger units.

14. A system for cooling a room containing one or more computer systems, said system comprising:

a plurality of heat exchanger units configured to receive cooling fluid through a cooling fluid line from an air conditioning unit for cooling the cooling fluid, said plurality of heat exchanger units being further configured to receive air through openings in the plurality of heat exchanger units, wherein said air is cooled through heat transfer with said cooling fluid in the plurality of heat exchanger units;

said plurality of heat exchanger units having at least one fan configured to cause air to flow into and flow out of the plurality of heat exchanger units;

a heat exchanger controller operable to control a supply of said cooling fluid to said plurality of heat exchanger units and operable to control the speed of the at least one fan;

one or more temperature sensors for sensing temperatures at one or more locations in the room;

an air conditioning unit controller configured to operate the air conditioning unit to vary the temperature of said cooling fluid delivered to the one or more locations in the room; and

a plurality of valves configured to meter the flow of cooling fluid through each of said plurality of heat exchanger units positioned along respective cooling fluid lines generally upstream of respective heat exchanger units, wherein said heat exchanger controller is operable to individually control the mass flow rate of said cooling fluid through said plurality of valves.

15. The system according to claim **14**, wherein said heat exchanger controller is operable to control the mass flow rate of said cooling fluid through a plurality of heat exchanger units in a substantially independent manner with respect to each of the plurality of heat exchanger units.

16. A system for cooling computer systems housed in one or more racks, said racks being maintained in a room, said system comprising:

means for receiving air from the room, said means for receiving air being located at a plurality of locations of the room;

means for cooling the received air in the plurality of means for receiving air, said plurality of means for cooling including means for receiving cooling fluid from an air conditioning unit;

means for delivering cooled air to said computer systems;

means for measuring temperatures at one or more locations in said room;

means for controlling delivery of said cooled air through said means for delivering cooled air in response to the temperature measurements;

means for controlling the temperature of said cooling fluid; and

means for individually manipulating a mass flow rate of the cooling fluid supplied to the plurality of means for receiving air, wherein the means for individually manipulating varies the mass flow rate of cooling fluid supplied to each of the plurality of means for receiving air in substantially independent manners.

17. The system according to claim **16**, further comprising:

means for controlling delivery of cooling fluid through said cooling means.

18. The system according to claim **16**, further comprising:

means for metering the flow of cooling fluid through said means for receiving air, said means for metering being positioned along respective cooling fluid lines configured to channel cooling fluid from the air conditioning unit to respective ones of the means for receiving air.

19. The system according to claim **16**, further comprising:

means for manipulating the mass flow rate of cooling fluid supplied to a plurality of means for receiving air in a substantially independent manner with respect to each of the plurality of means for receiving air.

20. A computer readable storage medium on which is embedded one or more computer programs [illegible]

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computer programs implementing a method for cooling a room configured to house a plurality of computer systems, said one or more computer programs comprising a set of instructions for:

supplying a plurality of heat exchanger unit configured to receive air from the room and to deliver air to the room with cooling fluid from an air conditioning unit;

cooling said received air through heat exchange with the cooling fluid in the plurality of heat exchanger units;

sensing temperatures at one or more locations in said room;

controlling at least one of the temperature of said cooling fluid and said air delivery by said plurality of heat exchanger units to said room in response to said sensed temperatures at said one or more locations; and

individually manipulating a mass flow rate of the cooling fluid supplied to the each of the plurality of heat exchanger units.

21. The computer readable storage medium according to claim **20**, said one or more computer programs further comprising a set of instructions for:

metering the flow of cooling fluid through said plurality of heat exchanger units with a valve positioned along respective cooling fluid lines configured to channel cooling fluid from the air conditioning unit to the plurality of heat exchanger units.

22. The computer readable storage medium according to claim **20**, said one or more computer programs further comprising a set of instructions for:

manipulating the mass flow rate of cooling fluid supplied to a plurality of heat exchanger units in a substantially independent manner with respect to each of the plurality of heat exchanger units.

* * * * *

EXHIBIT C

US006862179B2

(12) **United States Patent**
Beitelmal et al.

(10) **Patent No.: US 6,862,179 B2**
(45) **Date of Patent: Mar. 1, 2005**

(54) **PARTITION FOR VARYING THE SUPPLY OF COOLING FLUID**

(75) Inventors: **Abdlmonem H. Beitelmal**, Sacramento, CA (US); **Chandrakant D. Patel**, Fremont, CA (US)

(73) Assignee: **Hewlett-Packard Development Company, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 140 days.

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(22) Filed: **Nov. 26, 2002**

(65) **Prior Publication Data**

US 2004/0109288 A1 Jun. 10, 2004

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(52) **U.S. Cl.** **361/687**; 62/259.2; 454/195; 361/697
(58) **Field of Search** 361/679–687, 361/724–727, 695–697; 62/259.2, 186, 192, 81; 454/195; 312/223.1–223.3

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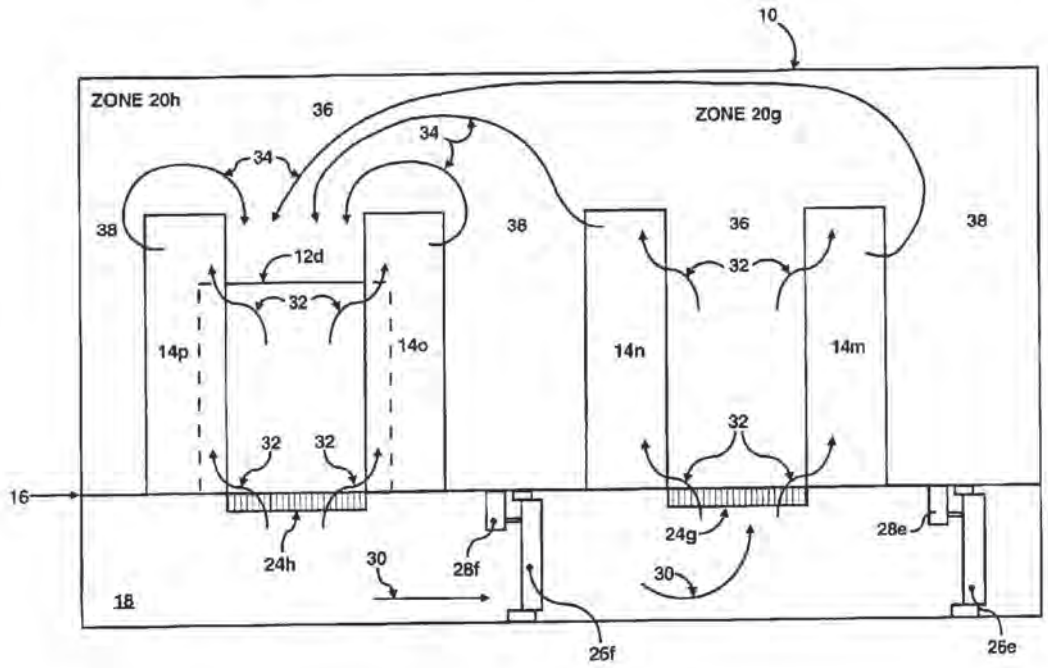
* cited by examiner

Primary Examiner—Hung Van Duong

(57) **ABSTRACT**

In a data center, a plurality of racks are cooled by activating a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of the data center. The zone includes at least one associated rack of the plurality of racks. In addition, the temperature of at least one associated rack is sensed and it is determined whether the sensed temperature is within a predetermined temperature range. Furthermore, the controllable partition is manipulated to vary the supply of the cooling fluid to the zone in response to the sensed temperature being outside the predetermined temperature range.

41 Claims, 8 Drawing Sheets



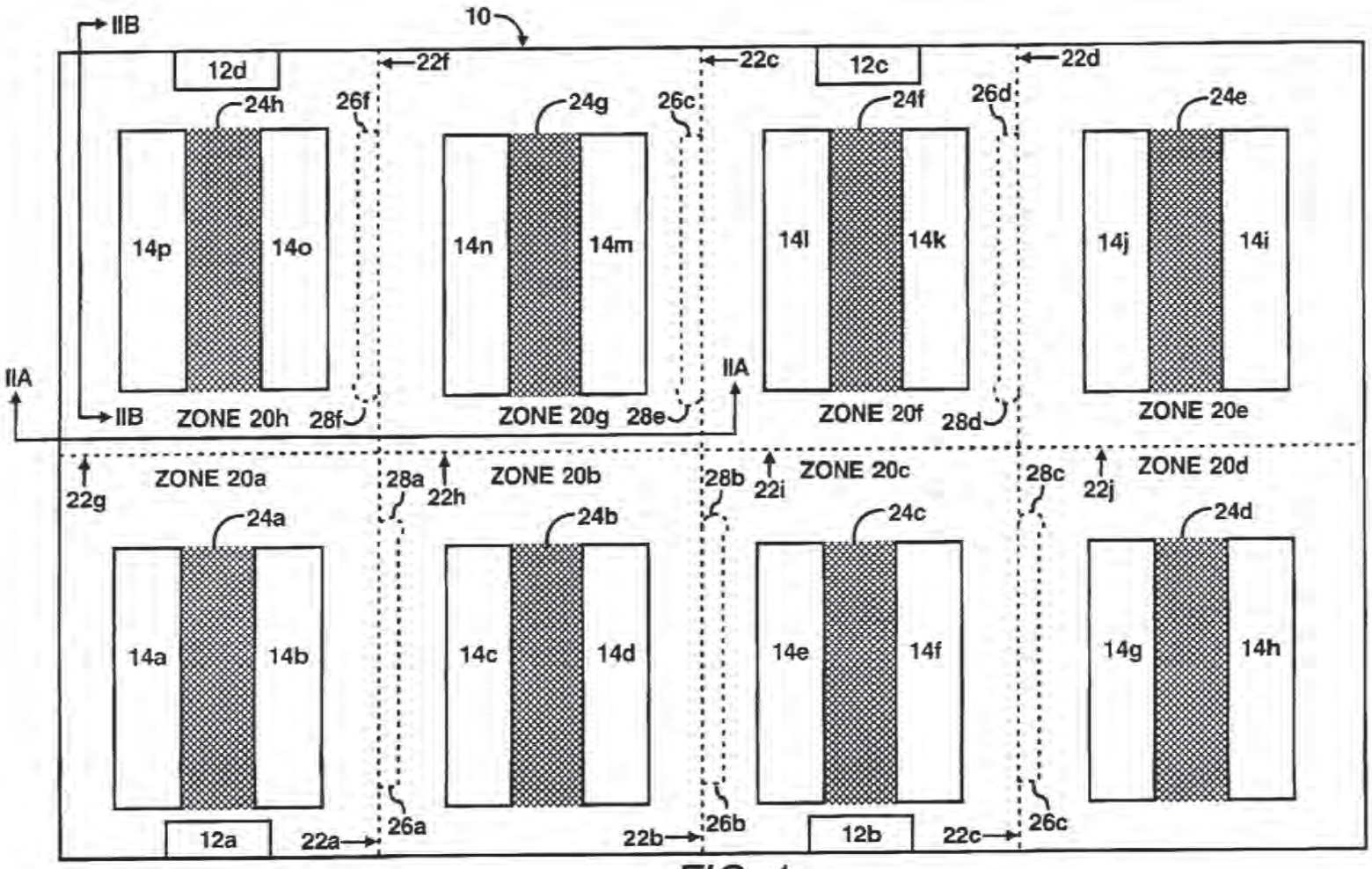

10
IIB
IIA
12d
12c
12a
12b
22f
22c
22d
22g
22h
22i
22j
22a
22b
22c
24h
24g
24f
24e
24a
24b
24c
24d
26f
26c
26d
26a
26b
26c
28f
28e
28d
28a
28b
28c
14p
14o
14n
14m
14l
14k
14j
14i
14a
14b
14c
14d
14e
14f
14g
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ZONE 20b
ZONE 20c
ZONE 20d

FIG. 1

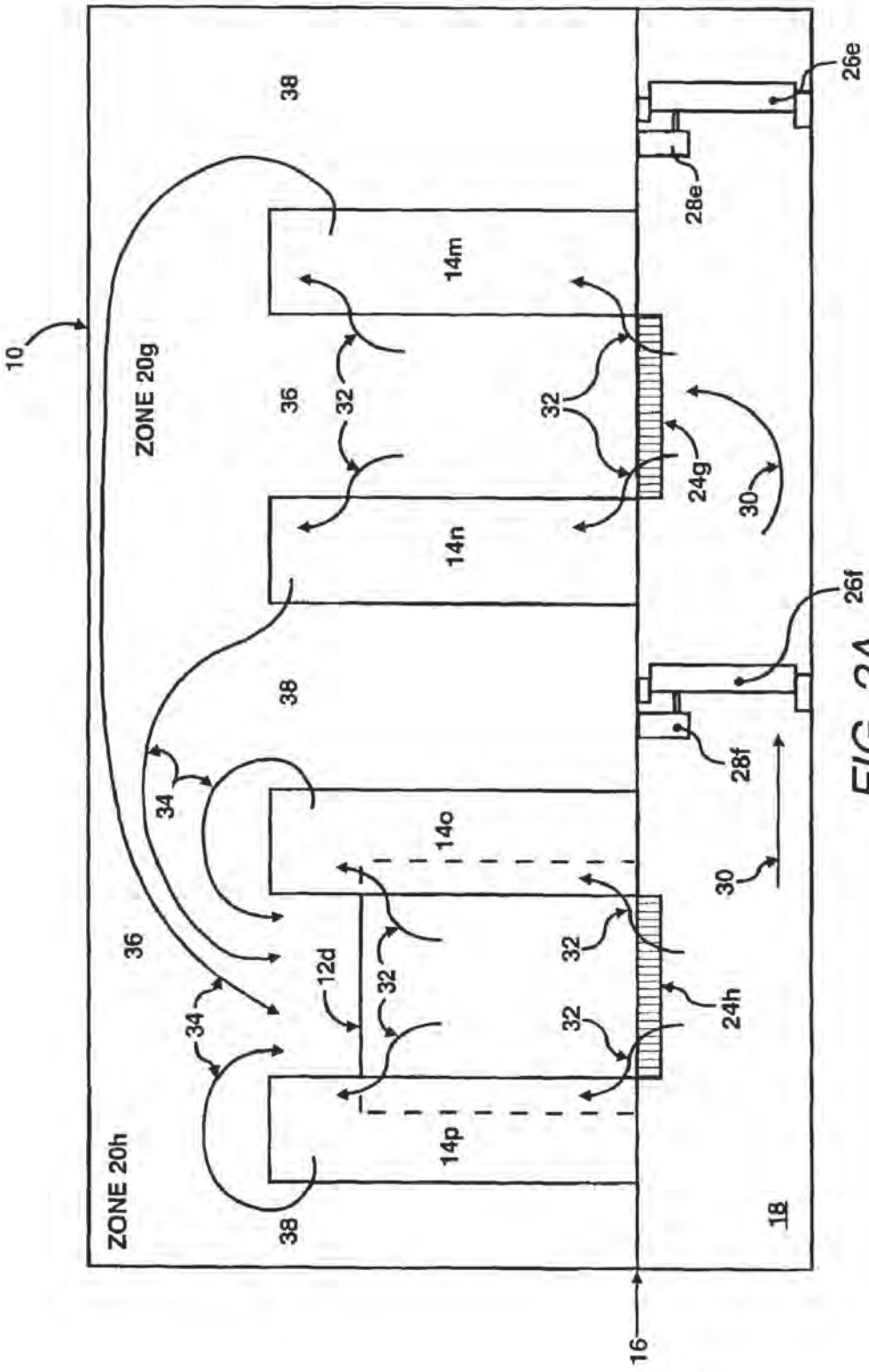

10
ZONE 20g
ZONE 20h
38
36
32
34
14m
14n
14o
14p
12d
24g
24h
26e
26f
28e
28f
30
18
16

FIG. 2A

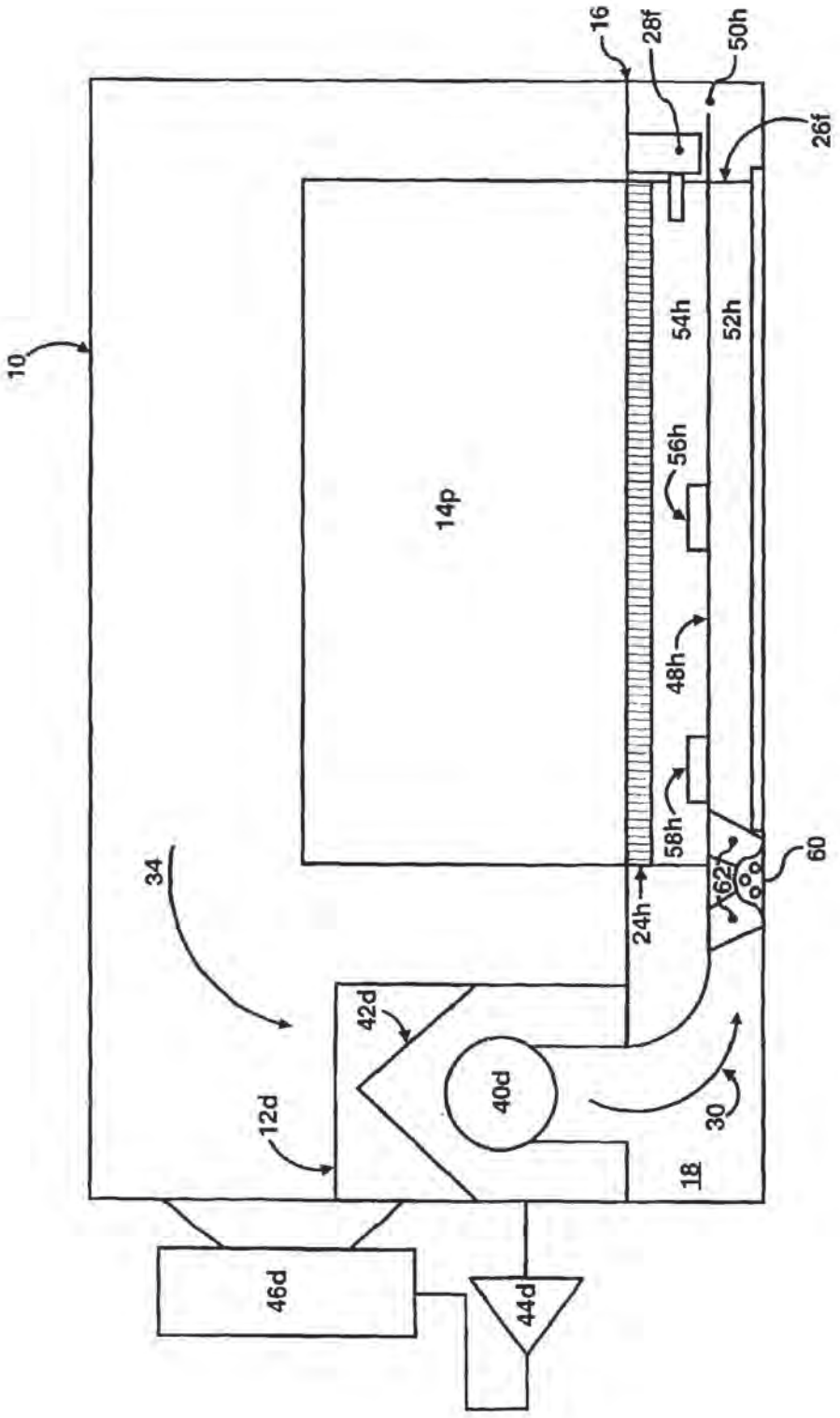

16
28f
50h
26f
10
54h
52h
56h
14p
48h
58h
60
62
34
24h
42d
40d
30
12d
18
46d
44d

FIG. 2B

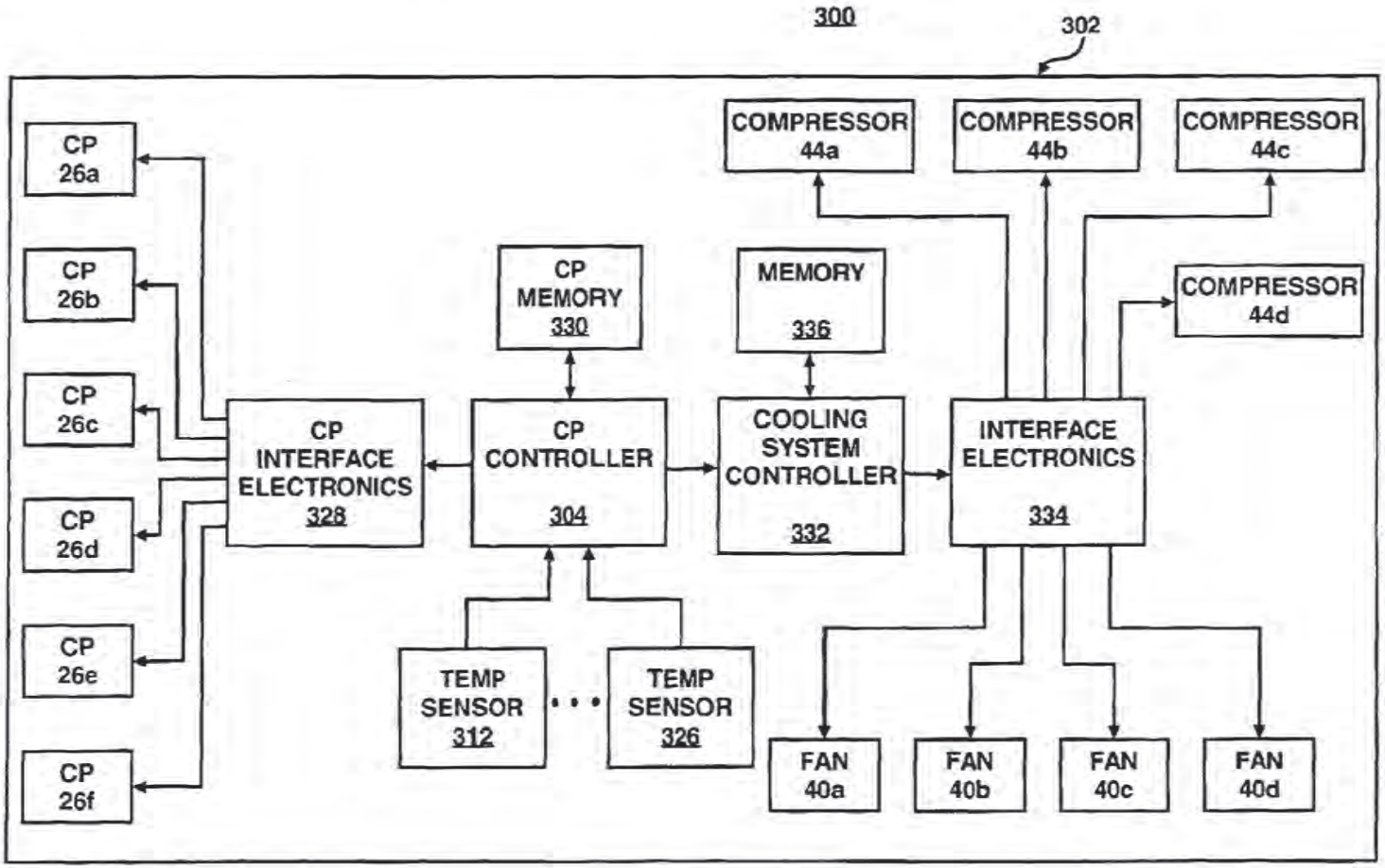

300
302
CP 26a
CP 26b
CP 26c
CP 26d
CP 26e
CP 26f
CP INTERFACE ELECTRONICS 328
CP MEMORY 330
CP CONTROLLER 304
MEMORY 336
COOLING SYSTEM CONTROLLER 332
INTERFACE ELECTRONICS 334
COMPRESSOR 44a
COMPRESSOR 44b
COMPRESSOR 44c
COMPRESSOR 44d
TEMP SENSOR 312
TEMP SENSOR 326
FAN 40a
FAN 40b
FAN 40c
FAN 40d

FIG. 3A

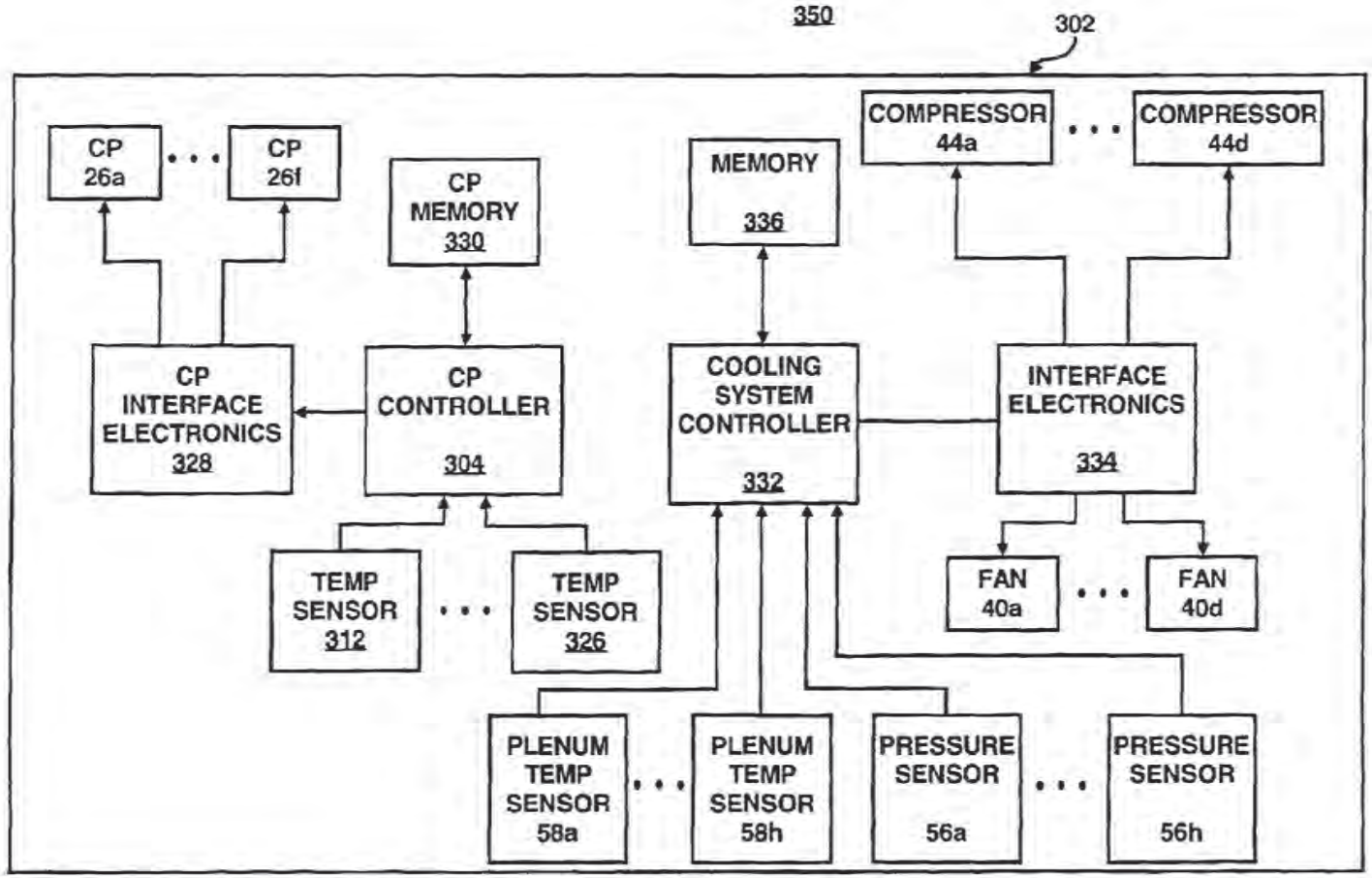

350
302
CP 26a
CP 26f
CP MEMORY 330
MEMORY 336
COMPRESSOR 44a
COMPRESSOR 44d
CP INTERFACE ELECTRONICS 328
CP CONTROLLER 304
COOLING SYSTEM CONTROLLER 332
INTERFACE ELECTRONICS 334
TEMP SENSOR 312
TEMP SENSOR 326
FAN 40a
FAN 40d
PLENUM TEMP SENSOR 58a
PLENUM TEMP SENSOR 58h
PRESSURE SENSOR 56a
PRESSURE SENSOR 56h

FIG. 3B

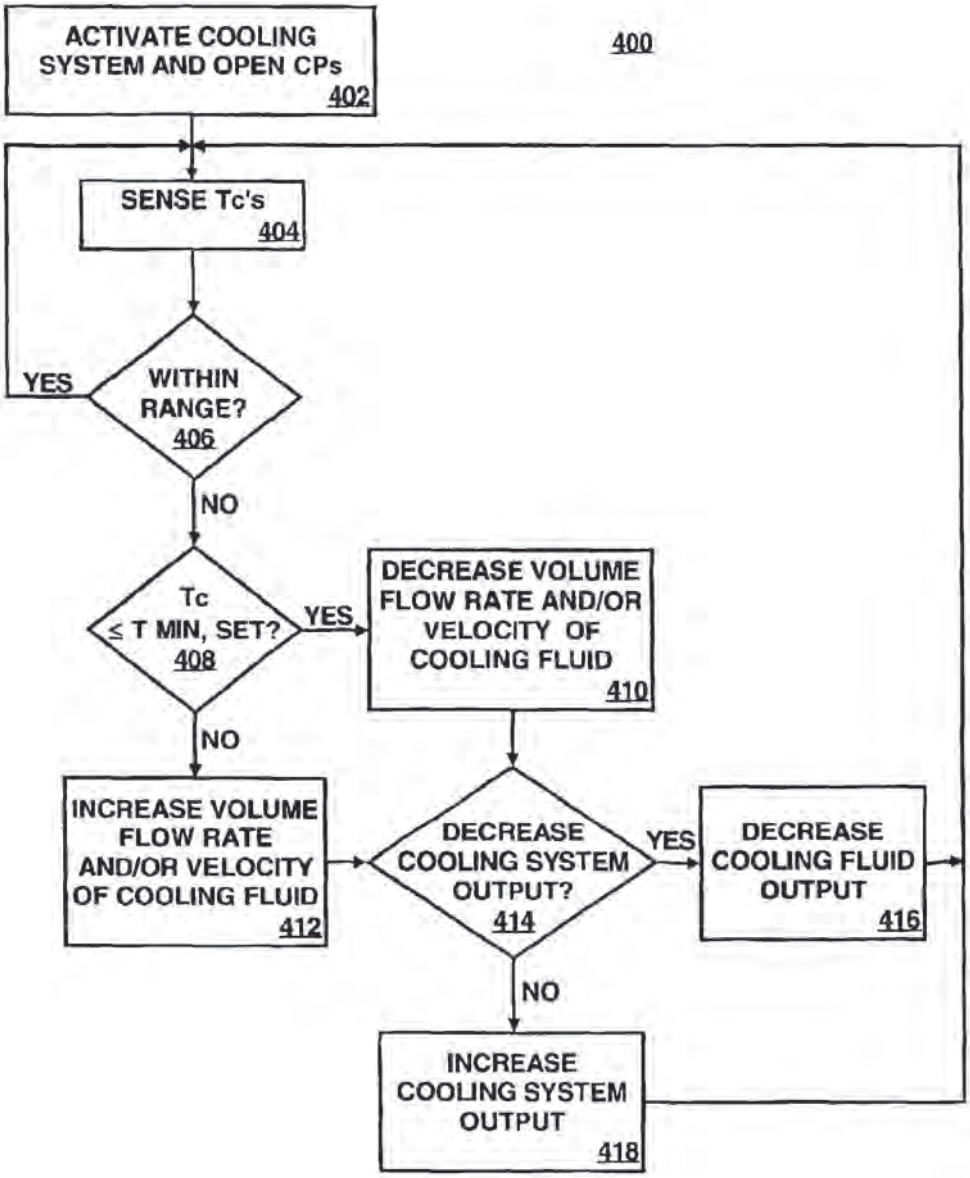

400
ACTIVATE COOLING SYSTEM AND OPEN CPs
402
SENSE Tc's
404
WITHIN RANGE?
406
YES
NO
Tc ≤ T MIN, SET?
408
YES
DECREASE VOLUME FLOW RATE AND/OR VELOCITY OF COOLING FLUID
410
NO
INCREASE VOLUME FLOW RATE AND/OR VELOCITY OF COOLING FLUID
412
DECREASE COOLING SYSTEM OUTPUT?
414
YES
DECREASE COOLING FLUID OUTPUT
416
NO
INCREASE COOLING SYSTEM OUTPUT
418

FIG. 4A

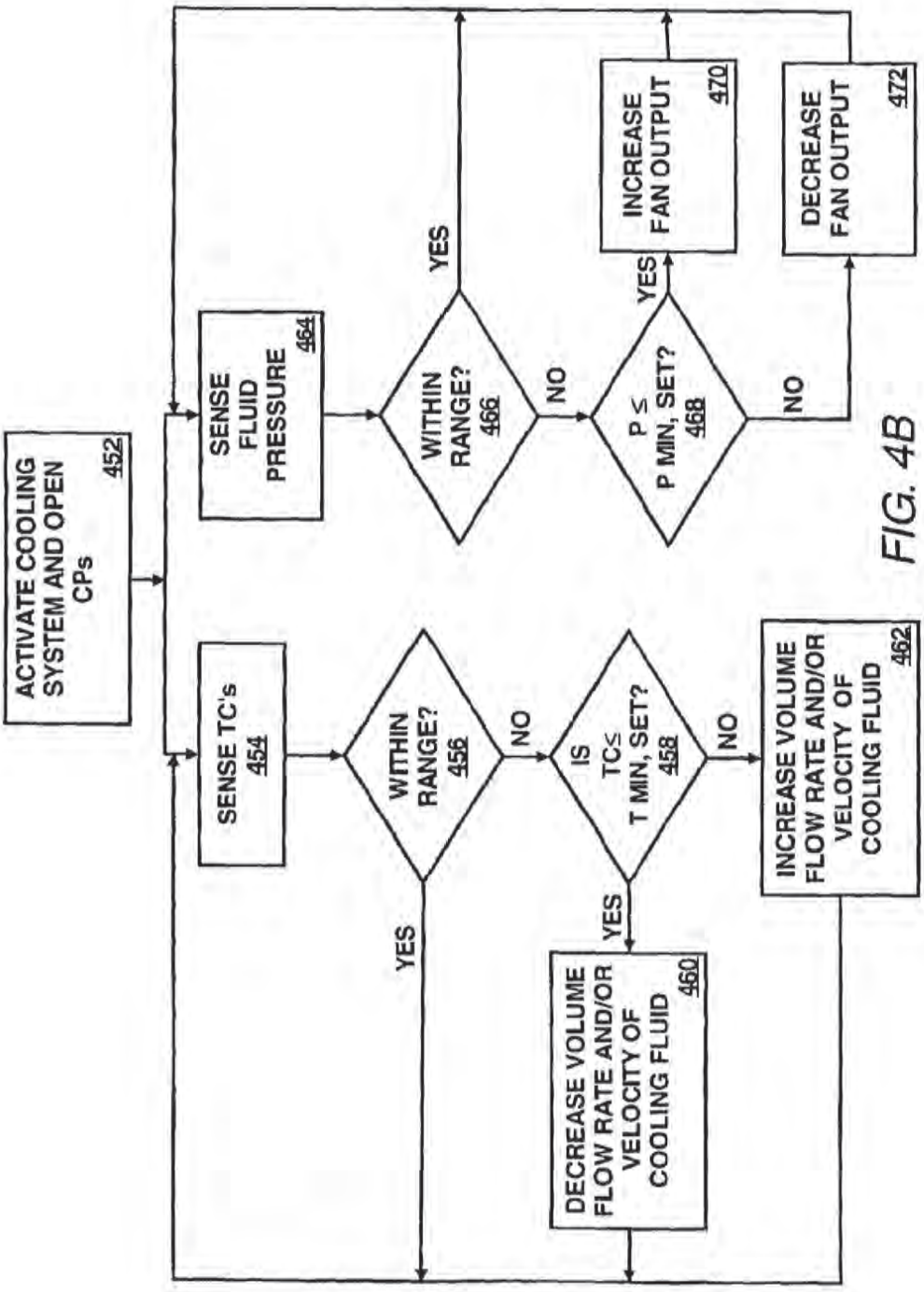


FIG. 4B

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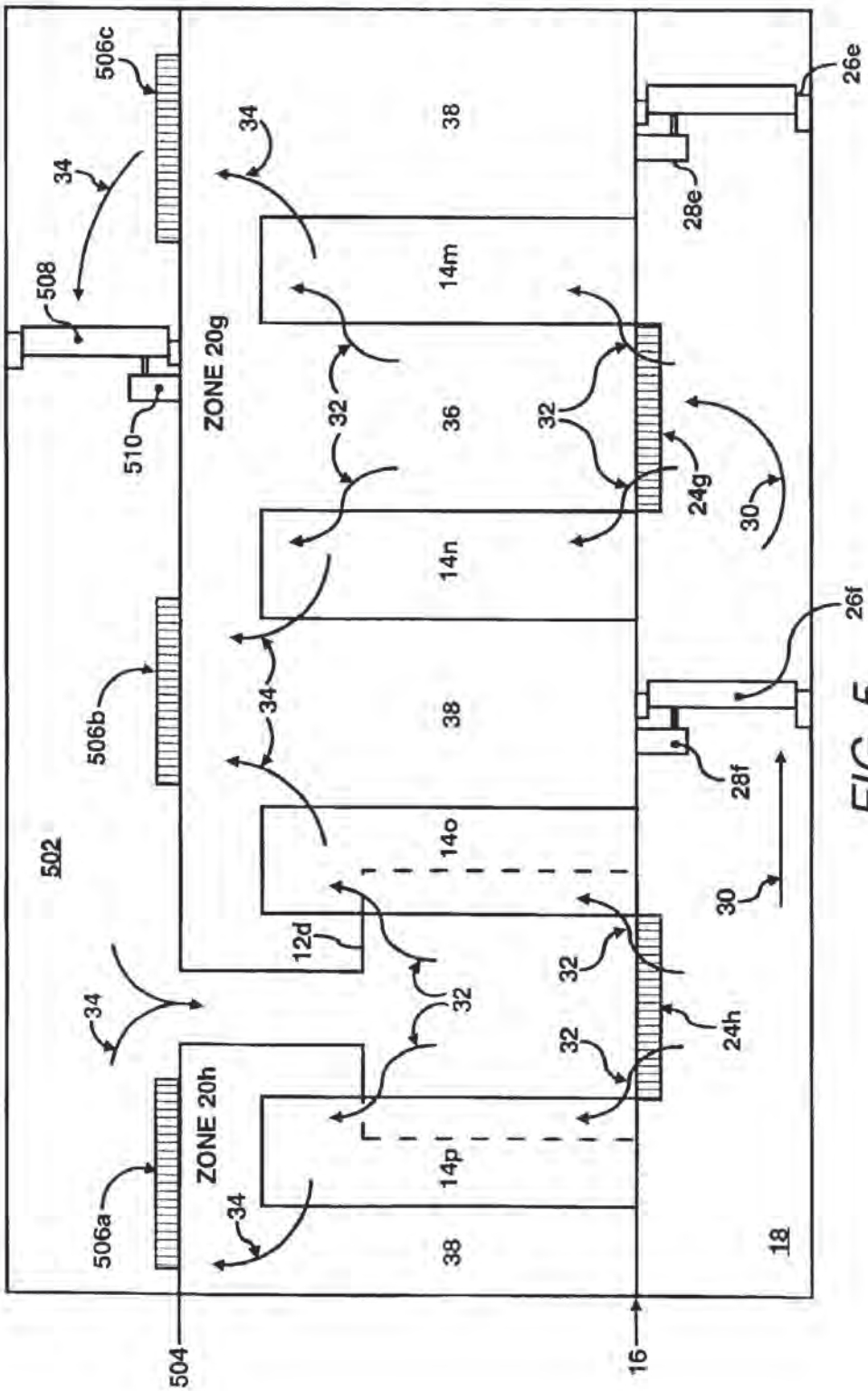

506c
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34
ZONE 20h
506a
14p
34
38
504
16
18
26e
28e
24g
30
26f
28f
30
32
24h

FIG. 5

PARTITION FOR VARYING THE SUPPLY OF COOLING FLUID

BACKGROUND

A data center may be defined as a location, e.g., room, that houses numerous printed circuit (PC) board electronic systems arranged in a number of racks. A standard rack may be defined as an Electronics Industry Association (EIA) enclosure, 78 in. (2 meters) wide, 24 in. (0.61 meter) wide and 30 in. (0.76 meter) deep. Standard racks may be configured to house a number of PC boards, e.g., about forty (40) boards, with future configurations of racks being designed to accommodate up to eighty (80) boards. The PC boards typically include a number of components, e.g., processors, micro-controllers, high speed video cards, memories, semi-conductor devices, and the like, that dissipate relatively significant amounts of heat during the operation of the respective components. For example, a typical PC board comprising multiple microprocessors may dissipate approximately 250 W of power. Thus, a rack containing forty (40) PC boards of this type may dissipate approximately 10 KW of power.

The power required to remove the heat dissipated by the components in the racks is generally equal to about 10 percent of the power needed to operate the components. However, the power required to remove the heat dissipated by a plurality of racks in a data center is generally equal to about 50 percent of the power needed to operate the components in the racks. The disparity in the amount of power required to dissipate the various heat loads between racks and data centers stems from, for example, the additional thermodynamic work needed in the data center to cool the air. In one respect, racks are typically cooled with fans that operate to move cooling fluid, e.g., air, across the heat dissipating components; whereas, data centers often implement reverse power cycles to cool heated return air. The additional work required to achieve the temperature reduction, in addition to the work associated with moving the cooling fluid in the data center and the condenser, often add up to the 50 percent power requirement. As such, the cooling of data centers presents problems in addition to those faced with the cooling of racks.

Conventional data centers are typically cooled by operation of one or more air conditioning units. The compressors of the air conditioning units typically require a minimum of about thirty (30) percent of the required cooling capacity to sufficiently cool the data centers. The other components, e.g., air movers (fans), etc., typically require an additional twenty (20) percent of the required cooling capacity. As an example, a high density data center with 100 racks, each rack having a maximum power dissipation of 10 KW, generally requires 1 MW of cooling capacity. Air conditioning units with a capacity of 1 MW of heat removal generally requires a minimum of 300 KW input compressor power in addition to the power needed to drive the air moving devices, e.g., fans, blowers, etc. Conventional data center air conditioning units do not vary their cooling fluid output based on the distributed needs of the data center. Instead, these air conditioning units generally operate at or near a maximum compressor power even when the heat load is reduced inside the data center.

The substantially continuous operation of the air conditioning units is generally designed to operate according to a worst-case scenario. That is, cooling fluid is supplied to the components at around 100 percent of the estimated cooling

requirement. In this respect, conventional cooling systems often attempt to cool components that may not be operating at a level which may cause its temperature to exceed a predetermined temperature range. In addition, conventional cooling systems generally supply cooling fluid to the components in an inefficient manner and substantially indiscriminate manner. That is, conventional cooling systems typically have plenums which may not vary the volume flow of cooling fluid according to fluctuations in the cooling requirements. Consequently, conventional cooling systems often incur greater amounts of operating expenses than may be necessary to sufficiently cool the heat generating components contained in the racks of data centers.

SUMMARY

According to one embodiment, the invention pertains to a method of cooling a plurality of racks in a data center. In this method, a cooling device is activated and a controllable partition configured to vary a supply of cooling fluid within a zone of the data center is opened. The zone includes at least one associated rack of the plurality of racks. In addition, the temperature of at least one associated rack is sensed and it is determined whether the sensed temperature is within a predetermined temperature range. Furthermore, the controllable partition is manipulated to vary the supply of the cooling fluid to the zone in response to the sensed temperature being outside the predetermined temperature range.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention are illustrated by way of example and not limitation in the accompanying figures in which like numeral references refer to like elements, and wherein:

FIG. **1** shows a simplified schematic illustration of a data center containing a cooling system in accordance with an embodiment of the invention;

FIG. **2**A shows a simplified schematic cross-sectional side view along lines IIA—IIA of FIG. **1** in accordance with an embodiment of the invention;

FIG. **2**B shows a simplified schematic cross-sectional side view along lines IIB—IIB of FIG. **1** in accordance with an embodiment of the invention;

FIGS. **3**A and **3**B each illustrate a block diagram of a control scheme for a cooling system according to various embodiments of the invention;

FIGS. **4**A and **4**B each show a flow diagram of a manner in which embodiments of the invention may be practiced; and

FIG. **5** shows a simplified schematic cross-sectional side view along lines IIA—IIA of FIG. **1** in accordance with another embodiment of the invention.

DETAILED DESCRIPTION

For simplicity and illustrative purposes, the principles of the invention are described by referring mainly to an embodiment thereof. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the invention. It will be apparent however, to one of ordinary skill in the art, that the invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the invention.

According to an embodiment of the invention, a cooling system is configured to adjust cooling fluid [illegible]

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gasses, liquid, etc.) flow to and/or from various racks located throughout a data center, e.g., a location that houses numerous printed circuit (PC) board electronic systems arranged in a number of racks, based upon the detected or anticipated temperatures at various locations throughout the data center. In one respect, by substantially increasing the cooling fluid flow to those racks dissipating greater amounts of heat and by substantially decreasing the cooling fluid flow to and/or from those racks dissipating lesser amounts of heat, the amount of energy required to operate the cooling system may be relatively reduced.

More specifically, by modifying the volume flow rate of cooling fluid from a plenum (e.g., supply plenum, return plenum, etc.) of the cooling system, an area of the data center may receive cooling capacity commensurate with the heat load dissipated within that area. In this regard, the volume flow rate of the cooling fluid is dependent upon the cross sectional area through which the fluid is flowing and the forces of pressure being exerted upon the fluid. Furthermore, by dynamically controlling the flow of cooling fluid with respect to the plenum (e.g., into, within, and out of), the ability to respond to various cooling demands may be maintained. Thus, instead of operating the devices, e.g., compressors, fans, etc., of the cooling system at substantially 100 percent of the anticipated heat dissipation from the racks, those devices may be operated in a more efficient manner. In addition, the racks may be positioned throughout the data center according to their anticipated heat loads to thereby enable computer room air conditioning (CRAC) units located at various positions throughout the data center to operate in a more efficient manner. In another respect, the positioning of the racks may be determined through implementation of modeling and metrology of the cooling fluid flow throughout the data center. In addition, the numerical modeling may be implemented to determine the volume flow rate and velocity of the cooling fluid flow through each of the one or more plenums. Furthermore, the numerical modeling may be implemented to determine the volume flow rate and velocity of the cooling fluid flow through supply and/or return vents.

FIG. **1** shows a simplified schematic illustration of a floor plan for a data center **10** containing a plurality of cooling systems **12***a*–**12***d*. The cooling systems **12***a*–**12***d* are operable to maintain a plurality of racks **14***a*–**14***p* within a predetermined temperature range. Although not explicitly shown in FIG. **1**, the data center **10**, according to this embodiment of the invention, includes a raised floor **16** (See FIG. **2**A). A pressurized enclosure **18** (See FIG. **2**A) is located beneath the raised floor **16**. Although the data center **10** is illustrated in FIG. **1** as containing sixteen racks **14***a*–**14***p* and four cooling systems **12***a*–**12***d*, it should be understood that the data center may include any number of racks, e.g., 100 racks, and cooling systems, e.g., one or more. Therefore, sixteen racks are for illustrative and simplicity of description purposes only and are not intended to limit the invention in any respect.

The racks **14***a*–**14***p* generally house a plurality of components (not shown), e.g., processors, micro-controllers, high speed video cards, memories, semi-conductor devices, and the like. The components may be elements of a plurality of subsystems (not shown), e.g., computers, servers, etc. The subsystems and the components may be implemented to perform various electronic, e.g., computing, switching, routing, displaying, and the like, functions. In the performance of these electronic functions, the components, and therefore the subsystems, generally dissipate relatively large amounts of heat. Because racks **14***a*–**14***p* have been generally known to include upwards of forty (40) or more subsystems, they may require substantially large amounts of cooling fluid to maintain the subsystems and the components generally within a predetermined operating temperature range. According to an embodiment of the invention, by substantially controlling the amount of cooling fluid delivered to the components and the subsystems located in the racks **14***a*–**14***p* based upon their respective heat loads, the power consumed by the cooling systems **12***a*–**12***d* to supply the cooling fluid may also be controlled.

In order to control the amount of cooling fluid delivered to the components and the subsystems located in the racks **14***a*–**14***p* based upon their respective heat loads, the pressurized enclosure **18** may be subdivided into a plurality of zones **20***a*–**20***h* by a plurality of partitions **22***a*–**22***j* (e.g., barriers, walls, etc.). In addition, according to an embodiment of the invention, the pressurized enclosure **18** may be configured to function as a plenum. In this regard, cooling fluid may enter the pressurized enclosure **18** below the cooling systems **12***a*–**12***d* and exit the pressurized enclosure **18** through a plurality of vents **24***a*–**24***h*. Furthermore, a plurality of controllable partitions ("CPs") **26***a*–**26***f* may be configured to control cooling fluid movement between the zones **20***a*–**20***h*. In various embodiments of the invention, the CPs **26***a*–**26***f* may include louvered, rotating and/or retractable partitions. Each of the CPs **26***a*–**26***f* may include a respective motor **28***a*–**28***f*. However, it is to be understood that any suitable actuating device may be substituted for some or all of the motors **28***a*–**28***f*. Examples of reasonable actuating devices include, but are not limited to, electromagnetic, pneumatic, and like devices.

In addition, although CPs are not shown in all of the partitions **22***a*–**22***j*, it is within the scope of the invention that some or all of the partitions **22***a*–**22***j* may include at least one controllable partition. Furthermore, although in the above description of the data center **10**, the raised floor **16** is mentioned, it is within the scope of the invention that a lowered ceiling and/or the raised floor **16** may be included in the data center.

In the following description, the operation of a subset of the cooling systems **12***a*–**12***d* are shown for simplicity and illustrative purposes. In particular, the operation of the cooling system **12***d* is discussed by way of example for the operation of cooling systems **12***a*–**12***d*.

FIG. **2**A shows a simplified schematic cross-sectional side view along lines IIA—IIA of FIG. **1** containing zones **20***g* and **20***h* in accordance with an embodiment of the invention. Although not shown in FIG. **2**A (See FIG. **2**B), the cooling system **12***d* may include a fan for supplying cooling fluid into the pressurized enclosure **18** (e.g., plenum). In this manner, as indicated by the arrow **30**, the cooling system **12***d* may supply cooling fluid into the pressurized enclosure **18**. Air is supplied into the cooling system **12***d* from the returned cooling fluid in the data center **10** as indicated by arrows **34**. In operation, the returned cooling fluid enters into the cooling system **12***d* as indicated by arrows **34** and is cooled by operation of various well know components of a cooling system (e.g., cooling coil, compressor, condenser, chilled water heat exchange, etc.) and/or in any reasonably suitable manner generally known to those of ordinary skill in the art. In addition, based upon the cooling fluid needed by the heat loads in the racks **14***m*–**14***p*, the cooling system **12***d* may be operated at various levels. For example, the capacity (e.g., the amount of work exerted on the refrigerant) of the compressor and the speed of the fan may both be modified to thereby control the temperature and the amount of cooling fluid flow delivered to the racks [illegible]

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respect, the compressor may be a variable capacity compressor and the fan may be a variable speed fan.

As the cooling fluid flows from the cooling system **12***d* and into the pressurized enclosure **18** as indicated by the arrow **30**, the flow of cooling fluid may be controlled by the CP **26***f*. In one respect, the velocity and the volume flow rate of the cooling fluid may be regulated by varying the shape and/or opening size of the CP **26***f*. Thus, according to this embodiment of the invention, the zones **20***h* and **20***g* may receive substantially individualized and localized amounts of cooling fluid according to the heat loads of the respective racks **14***m*–**14***p* within each zone **20***h* and **20***g*. For example, if the racks **14***m* and **14***n* in zone **20***g* are generating relatively little heat load as compared to racks **14***o* and **14***p* in zone **20***h*, the CP **26***f* may be controlled to reduce the velocity and/or volume flow rate of the cooling fluid being conveyed therethrough. In this manner, the volume flow rate of cooling fluid available to flow through the vents **24***h* and **24***g* may be modified.

The arrows **32** indicate the general direction of travel of the cooling fluid into the racks **14***m*–**14***p* and the arrows **34** indicate the general direction of travel of fluid heated by the heat dissipating components located within the racks **14***m*–**14***p*. As may be seen in FIG. **2**A, the areas between the racks **14***m*–**14***p* may comprise either cool aisles **36** or hot aisles **38**, or a combination thereof. The cool aisles **36** are those aisles that include the vents **24***g* and **24***h* and thus receive cooling fluid for delivery to the racks **14***m*–**14***p*. The hot aisles **38** are those aisles that receive air heated by the heat dissipating components in the racks **14***m*–**14***p*.

In addition to controlling the flow of cooling fluid by controlling the CP **26***f*, it is within the scope of the invention that flow of cooling fluid may also be controlled by the manipulation of dynamically controllable vents. In this regard, the vents **24***h* and **24***g* may be dynamically controllable vents and may be operated to control the velocity and the volume flow rate of the cooling fluid therethrough. Furthermore, various sections of each of the racks **14***m*–**14***p* may also receive substantially individualized amounts of cooling fluid. By way of example, if the bottom halves of the racks **14***m* and **14***n* are operating at maximum power, thereby dissipating a maximum level of heat load, and the upper halves are operating at little or no power, the vent **24***g* may be configured to enable cooling fluid flow therethrough to have a relatively high volume flow rate with a relatively low velocity. In this manner, the cooling fluid may operate to generally supply greater cooling to the lower halves of the racks **14***m* and **14***n*, whereas the upper halves may receive relatively lesser amounts of cooling fluid. In addition, if the upper halves of the racks **14***o* and **14***p* are operating at approximately 50 percent of their maximum power, and the lower halves are operating at little or no power, the vent **24***h* may be configured to enable cooling fluid flow therethrough to have a relatively low volume flow rate with a relatively high velocity. In this manner, the cooling fluid flow may have sufficient momentum to adequately reach and cool the upper halves of the racks **14***o* and **14***p*. In one respect, therefore, the amount of energy consumed by the cooling system **12***d* in maintaining the racks **14***m*–**14***p* at a predetermined temperature range may be substantially reduced in comparison with conventional data center cooling systems.

A more detailed description of the above-described embodiment may be found in co-pending U.S. application Ser. No. 09/970,707, filed Oct. 5, 2001, which is assigned to the assignee of the present invention and is incorporated by reference herein in its entirety.

In the following description, the operation of a subset of the cooling systems **12***a*–**12***d* is shown for simplicity and illustrative purposes.

FIG. **2**B shows a simplified schematic cross-sectional side view along lines IIB—IIB of FIG. **1** containing zone **20***h* in accordance with an embodiment of the invention. The cooling system **12***d* generally includes a fan **40***d* for supplying cooling fluid (e.g., air) into the pressurized enclosure **18**. Air, heated in the data center **10** is supplied to the fan **40***d* as indicated by an arrow **34**. In operation, the returned cooling fluid (e.g., heated air, return air, etc.) enters into the cooling system **12** as indicated by the arrow **34** and is cooled by operation of a cooling coil **42***d*, a compressor **44***d*, and a condenser **46***d*, in any reasonably suitable manner generally known to those of ordinary skill in the art. As described hereinabove, in an embodiment of the invention, the compressor **44***d* may be a variable capacity compressor and/or the fan **40***d* may be a variable speed fan. Although a compressor **44***d* is illustrated, it is to be understood that any reasonably suitable cooling device may be implemented to cool the cooling fluid e.g., chilled water heat exchange and the like.

According to an embodiment of the invention, the cooling fluid supply for flow through the vent **24***h* may be maintained at a relatively uniform pressure. In this respect, the pressurized enclosure **18** may include a divider **48***h*. The length of the divider **48***h* may extend substantially along the entire length of pressurized enclosure **18**, i.e., in the direction generally perpendicular to the plane of FIG. **2**B. The width of the divider **48***h* may be configured to extend from the cooling system **12***d* to substantially the end of the pressurized enclosure **18** to thus create a gap **50***h* between a side edge of the divider **48***h* and a side surface of the pressurized enclosure **18**. The divider **48***h* generally divides the pressurized enclosure **18** into two relatively separate chambers **52***h*, **54***h*. The first chamber **52***h* is in fluid communication with the outlet of the fan **40***d*. The second chamber **54***h* is in fluid communication with the first chamber **54***h* substantially through the gap **50***h*. In this respect, the cooling fluid flow originating from the fan **40***d* must travel substantially the entire width of the pressurized enclosure **18**, i.e., through the first chamber **52***h*, for the fluid flow to enter into the second chamber **54***h*.

The cooling fluid in the second chamber **54***h* may be maintained at a substantially uniform static pressure by virtue of the manner in which the cooling fluid is introduced into the second chamber **54***h*. The rate at which the cooling fluid is supplied into the first chamber **52***h* by the fan **40***d* may cause a relatively large amount of turbulence in the cooling fluid located in the first chamber **52***h*. The turbulence is generally greatest at the outlet of the fan **40***d* and generally decreases as the distance from the outlet increases. By virtue of the distance the cooling fluid must travel to enter into the second chamber **54***h*, the cooling fluid may have substantially stabilized, thus enabling the cooling fluid entering into the second chamber **54***h* to be relatively calm. In this respect, the divider **48***h* operates to provide a relatively consistent cooling fluid pressure supply for the vent **24***h*.

The pressure of the cooling fluid located in the second chamber **54***h* may be measured by a pressure sensor **56***h*. In this respect, the pressure sensor **56***h* may detect any discernable changes in the pressure of the cooling fluid located within the second chamber **54***h* and relay that information to a cooling system controller (not shown). Similarly, pressure sensors **56***a*–**56***g* (not shown) may detect any discernable changes in the pressure of the cooling fluid located within the respective chambers **54***a*–**54***g* and relay that information to the cooling system controller. The cooling system controller may operate to alter the output [illegible]

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response to the detected changes in pressure. Therefore, operation of the fan **40***d* may be related to the cooling requirements of the racks **14***a* (See FIG. **2**A) and **14***p* within the zone **20***h* and thus, the amount of energy required to supply the zone **20***h* with cooling fluid may be substantially optimized. In one respect, only that amount of energy required to substantially cool the components contained in the zone **20***h* may be expended, which may correlate to a substantial energy savings over known cooling systems.

More generally, by controlling the operation of the CPs **26***a*–**26***f* (See FIG. **1**), operation of the cooling systems **12***a*–**12***d* may be related to the cooling requirements of each of the zones **20***a*–**20***h* and the amount of energy required to supply the racks **14***a*–**14***p* with cooling fluid may be substantially optimized. For example, if racks **14***i*, **14***j*, **14***o*, and **14***p* are substantially idle, the CPs **26***d* and **26***f* may be controlled to substantially stop the flow of cooling fluid, while the CP **26***e* is controlled to allow the flow of cooling fluid. In this manner, cooling system **12***d* may be essentially shut off while cooling system **12***c* is utilized to cool zones **20***f* and **20***g*. Thus, in another respect, only that amount of energy required to substantially cool the components contained within each zone **20***a*–**20***h* may be expended, which may correlate to a substantial energy savings over known cooling systems.

The capacity of the compressor **44***d* may vary according to changes in the temperature of the cooling fluid located in the second chamber **54***h*. As such, a plenum temperature sensor **58***h* may be located within the second chamber **54***h* to relay temperature measurements to the cooling system **12***d*. The plenum temperature sensor **58***h* may comprise any reasonably suitable temperature sensor known to those skilled in the art. Therefore, the compressor **44***d* may be operated to generally maintain the temperature of the cooling fluid within the second chamber **54***h* at a substantially constant level. In addition, the capacity of the compressor **44***d* may also vary according to detected and/or anticipated changes in heat loads generated in the racks **14***o* and **14***p*. As an example, the compressor **44***d* capacity may be increased as the heat loads generated in the racks **14***o* and **14***p* increase. Furthermore, as the second chambers **54***a*–**54***g* (not shown) may also include respective plenum temperature sensors **58***a*–**58***g* (not shown), the capacity of the compressors **44***a*–**44***d* (compressors **44***a*–**44***c* not shown) may also vary according to detected and/or anticipated changes in heat loads generated in the racks **14***a* and **14***p*. In this regard, the power required to operate the compressors **44***a*–**44***d* may be substantially optimized, thereby reducing the total power required to operate the cooling systems **12***a*–**12***d*.

The compressors **44***a*–**44***d* may thus be controlled to either increase or decrease the mass flow rate of a refrigerant therethrough. Because the specific type of compressors **44***a*–**44***d* and fans **40***a*–**40***d* to be employed with the embodiments of the invention may vary according to individual needs, the invention is not limited to any specific type of compressor or fan. Instead, any reasonably suitable types of compressors **44***a*–**44***d* and fans **40***a*–**40***d* that are capable of accomplishing certain aspects of the invention may be employed with the embodiments of the invention. The choice of compressors **44***a*–**44***d* and fans **40***a*–**40***d* may depend upon a plurality of factors, e.g., cooling requirements, costs, operating expenses, etc.

Although the description above pertains to cooling systems that employ compressors, it should be understood that embodiments of the invention may implement cooling systems having other types of cooling devices, e.g., water chilled heat exchangers and the like.

Various obstructions **60** such as wires and communication lines may be located in the pressurized enclosure **18** beneath the raised floor **16**. These obstructions may increase turbulence. In order to minimize this turbulence, one or more baffles **62** may be placed over the obstruction **60**. The baffle **62** is generally operable to generate an essentially laminar (e.g., smooth, non-turbulent, etc.) flow of cooling fluid. For example, the baffle **62** may be constructed from a plurality of tubes (not shown) aligned in the direction of fluid flow. These tubes may be configured in a honeycomb or other such pattern. Furthermore, it is within the scope of the invention that the baffle **62** or similar structure be configured to rotate about an axis and controlled by an actuator (not shown). In this manner, the direction of cooling fluid flowing within the pressurized enclosure **18** may be modulated. For example, the baffle **62** may be controlled to direct cooling fluid toward a subset (e.g., left, right, center, etc.) of the pressurized enclosure **18** in response to increased cooling needs in the corresponding subset of the zone **20***a*–**20***h*. In another example, the baffle **62** may be controlled to direct the flow of cooling fluid upwards (e.g., out of a vent **24***a*–**24***h*) or downwards (e.g., to increase the flow towards a partition **26***a*–**26***f*).

Referring to FIG. **3**A, there is illustrated a block diagram **300** of a control scheme for a cooling system **302** according to an embodiment of the invention. The following description of the block diagram **300** is one manner in which the cooling system **302** may be operated. In this respect, it is to be understood that the following description of the block diagram **300** is but one manner of a variety of different manners in which such a cooling system **302** may be operated.

A CP controller **304** is generally configured to control the operation of the CPs **26***a*–**26***f*. In this regard, the CP controller **304** may comprise a microprocessor, a microcontroller, an application specific integrated circuit (ASIC), and the like. The manner in which the CP controller **304** operates the CPs **26***a*–**26***f*, i.e., the flow of cooling fluid therethrough, may be predicated upon the detected or anticipated temperatures of the racks **14***a*–**14***p* (See FIG. **1**) or portions thereof. For example, with regard to detected temperatures, a plurality of temperature sensors **312**–**326**, e.g., thermocouples, may be positioned at various positions around the subsystems and/or the racks **14***a*–**14***p*. One or more of the temperature sensors **312**–**326** may correspond to a respective zone **20***a*–**20***h* within the data center **10**. By way of example, the temperature detection by one temperature sensor **312** may result in a corresponding modulation of one CP **26***a* and/or the temperature detection by one temperature sensor **312** may result in the modulation of a plurality of CPs **26***a*–**26***c*. Alternatively, with regard to anticipated temperatures, anticipated cooling requirements for each of the racks **14***a*–**14***p* and/or various sections of the racks may be predicated upon an impending load on the racks **14***a*–**14***p* and/or sections of the racks. For example, the CP controller **304** may be connected to another controller, e.g., a central controller for the subsystems, which anticipates the heat load the components and/or the subsystems will dissipate. This information may be relayed to the CP controller **304** which may then manipulate the CPs **26***a*–**26***f* according to the anticipated load.

Although FIG. **3**A illustrates eight temperature sensors **312**–**326**, it should be understood that the number of temperature sensors is not critical to the operation of the embodiment of the invention. Instead, the cooling system **302** may include any reasonably suitable number of temperature sensors to thus measure the temperature [illegible]

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reasonably suitable number of racks **14***a*–**14***p* or portions thereof. The number of temperature sensors and the temperature measurements of the number of racks may be upgradable, e.g., scalable, to include any additional components and/or racks that may be included in the data center **10**. In addition, the temperature sensors need not be stationary. In this regard, according to another embodiment of the invention, a mobile device (not shown) is implemented to gather or measure at least one local environmental condition (e.g., temperature, air flow, humidity, etc.) in the data center **10**. More particularly, the mobile device is configured to travel around the racks to determine the one or more environmental conditions at various locations throughout the data center. In addition, the device may be configured to detect the one or more environmental conditions at various heights throughout the data center.

A more detailed description of the above-described embodiment may be found in co-pending U.S. application Ser. No. 10/157,892, filed May 31, 2002, which is assigned to the assignee of the present invention and is incorporated by reference herein in its entirety.

If there is an actual detected change or an anticipated change in the temperature of the respective racks **14***a*–**14***p* and/or portions thereof, the CP controller **304** generally operates to manipulate the corresponding one or more CP **26***a*–**26***f* to compensate, i.e., changes the volume flow rate, velocity, and other similar characteristics of the cooling fluid, for the change in temperature. In this respect, each of the zones **20***a*–**20***h* and/or portions thereof generally receives substantially only the amount of cooling fluid necessary to maintain the temperature of the portions of the respective racks therein to within a predetermined temperature range. As will be seen from the discussion hereinbelow, by controlling the cooling fluid flow in this manner, the compressors **44***a*–**44***d* and fans **40***a*–**40***d* may be operated at substantially optimized levels, thereby decreasing the amount of energy and thus the operating costs required to operate these devices.

CP interface electronics **328** may be provided to act as an interface between the CP controller **304** and the components, e.g., control the opening in the CPs **26***a*–**26***f* and the direction of cooling fluid flow through the CPs **26***a*–**26***f*, etc, for operating the CPs **26***a*–**26***f*.

The CP controller **304** may also be interfaced with a CP memory **330** configured to provide storage of a computer software that provides the functionality of the cooling system and may be executed by the CP controller **304**. The memory **320** may also be configured to provide a storage for containing data/information pertaining to the manner in which each of the CPs **26***a*–**26***f* may be manipulated in response to the detected and/or anticipated temperatures of the portions of the racks **14***a*–**14***p*. In keeping with the example cited hereinabove, the CP controller **304** may operate the CP **26***a* to increase the volume flow rate and decrease the velocity of the cooling fluid flowing therethrough in response to a detected increase in the heat load of a lower portion of a corresponding rack. The memory **320** may be implemented as a combination of volatile and non-volatile memory, such as dynamic random access memory (DRAM), EEPROM, flash memory, and the like.

The CP controller **304** may be configured to relay data/information pertaining to the flow of cooling fluid through the CPs **26***a*–**26***f* to a cooling system controller **332**. The cooling system controller **332** is generally configured to control the operation of the cooling system **302**. In this regard, the cooling system controller **332** may comprise a microprocessor, a micro-controller, ASIC, and the like.

Interface electronics **334** may be provided to act as an interface between the cooling system controller **332** and the components for operating the compressors **44***a*–**44***d* and the fans **40***a*–**40***d*, e.g., the supply of voltage to vary the respective speeds of the compressors and the fans, direct control of each compressor and the fan, etc.

The cooling system controller **332** may also be interfaced with a memory **336** configured to provide storage of a computer software that provides the functionality of the cooling system **302**, and may be executed by the cooling system controller **332**. The memory **336** may also be configured to provide a storage for containing data/information pertaining to the manner in which the compressors **44***a*–**44***d* and the fans **40***a*–**40***d* may be manipulated in response to variations in the cooling fluid flow through the CPs **26***a*–**26***f*. In keeping with the example cited hereinabove, the cooling system controller **332** may operate the compressor **44***a* and the fan **40***a* to increase/decrease the volume flow rate of the cooling fluid flow in response to various degrees of detected increases/decreases in the volume flow rate through the CP **26***a*, or using correlations thereof. More particularly, a look up table (not shown) may be stored in the memory **336**. By way of example, the look up table may include information pertaining to the level of compressor **44***a* speed and fan **40***a* output increase necessary for a detected increase in the volume flow rate. In this respect, the compressor **44***a* speed and the fan **40***a* output may be varied substantially incrementally in response to detected changes in the volume flow rate. The memory **336** may be implemented as a combination of volatile and non-volatile memory, such as dynamic random access memory (DRAM), EEPROM, flash memory, and the like.

Although FIG. **3**A illustrates a single CP controller **304** configured to operate the CPs **26***a*–**26***f*, it should be understood that a plurality of CP controllers may be implemented to perform the functions of the CP controller **304** without deviating from the scope and spirit of the invention.

In FIG. **3**B, there is illustrated a block diagram **350** of a control scheme for a cooling system **302** according to another embodiment of the invention. The elements illustrated in the block diagram **350** operate in substantially the same manner as those elements illustrated in the block diagram **300**. However, one difference lies in the substantially independent operability of the cooling system controller **332**. That is, operation of the cooling system controller **332** may not be directly related to the operation of the CP controller **304**. Because of the apparent similarities between the block diagrams **300** and **350**, only those elements that differ between the block diagrams will be described hereinbelow.

The pressure sensors **56***a*–**56***h* are configured to measure the pressure within the second chambers **54***a*–**54***h* of the pressurized enclosure **18** as described hereinabove. The pressure measurements and/or any discernable changes in the pressure measurements obtained by the pressure sensors **56***a*–**56***h* may be relayed to the cooling system controller **332**. In addition, the plenum temperature sensors **58***a*–**58***h* may be configured to measure the temperature of the fluid within the second chambers **54***a*–**54***h*. The temperature measurements and/or any discernable changes in the temperature obtained by the plenum temperature sensors **58***a*–**58***h* may also be relayed to the cooling system controller **332**.

The cooling system controller **332** may manipulate the capacity of the compressors **44***a*–**44***d* based upon the measured temperature of the fluid. That is, the cooling system

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fluid within the second chambers **54***a*–**54***h* may be maintained at a substantially constant level by manipulation of the compressors. Further, the output of the fans **40***a*–**40***h* may be manipulated based upon the measured pressure of the fluid in the second chambers **54***a*–**54***h* to vary the amount of cooling fluid supplied and to thereby substantially maintain the pressure of the cooling fluid within the second chambers **54***a*–**54***h* at a substantially uniform level. Thus, the cooling system controller **332** is operable to individually increase the speed of the compressors **44***a*–**44***d* and the fans **40***a*–**40***h* output, e.g., expend a greater amount of energy, substantially as the heat loads in the racks **14***a*–**14***p* requires such an increase.

For example, the cooling system controller **332** may increase the compressor **44***d* speed and fan **40***d* output by a relatively large amount in response to a relatively large decrease in the measured pressure by the pressure sensor **56***g* (although not explicitly shown, sensor **56***g* is indicated by the ellipsis between **56***a* and **56***h*) if the CP **26***f* is open. However, if the CP **26***f* is closed and the CP **26***e* is open, the cooling system controller **332** may increase the compressor **44***c* speed and fan **40***c* output by a relatively large amount in response to a relatively large decrease in the measured pressure by the pressure sensor **56***g*.

In a further example, in a situation where the cooling fluid demands of zone **20***g* exceed the cooling capacity of a subset of the cooling system **302** (e.g., one or a few of the compressors **44***a*–**44***d* and the fans **40***a*–**40***d*), the cooling system controller **332** may be configured to increase the output of a relatively larger subset of the cooling system **302** and control appropriate CPs **26***a*–**26***f* to increase the flow of cooling fluid to the zone **20***g*. In this respect, the pressure within the second chamber **54***g* (although not explicitly shown, chamber **54***g* is indicated by the ellipsis between **54***a* and **54***h*) may be maintained at a substantially uniform level even when the pressures change by a relatively sharp amount. Consequently, the compressors **44***a*–**44***d* and the fans **40***a*–**40***d* are not operated at a substantially constant energy level and the amount of energy necessary is substantially lower than that of conventional cooling systems that typically operate at maximum energy levels.

The memory **336** may also be configured to store data/information pertaining to the control of the individual compressors' **44***a*–**44***d* speeds and the outputs of the fans, **40***a*–**40***d* corresponding to the measured pressure with the respective second chambers **54***a*–**54***h*.

FIG. **4**A shows a flow diagram **400** of a manner in which an embodiment of the invention may be practiced. The following description of the flow diagram **400** is made with reference to the block diagram **300** illustrated in FIG. **3**A, and thus makes reference to the elements cited therein. It is to be understood that the steps illustrated in the flow diagram **400** may be contained as a utility, program, subprogram, in any desired computer accessible medium. In addition, the flow diagram **400** may be embodied by a computer program, which can exist in a variety of forms both active and inactive. For example, they can exist as software program(s) comprised of program instructions in source code, object code, executable code or other formats. Any of the above can be embodied on a computer readable medium, which include storage devices and signals, in compressed or uncompressed form.

Examples of computer readable storage devices include conventional computer system RAM (random access memory), ROM (read only memory), EPROM (erasable, programmable ROM), EEPROM (electrically erasable, programmable ROM), and magnetic or optical disks or tapes. Examples of computer readable signals, whether modulated using a carrier or not, are signals that a computer system hosting or running the computer program can be configured to access, including signals downloaded through the Internet or other networks. Concrete examples of the foregoing include distribution of the programs on a CD ROM or via Internet download. In a sense, the Internet itself, as an abstract entity, is a computer readable medium. The same is true of computer networks in general. It is therefore to be understood that those functions enumerated below may be performed by any electronic device capable of executing the above-described functions.

In the flow diagram **400**, the cooling system **302** is activated and the CPs **26***a*–**26***f* are opened at step **402**. The temperature of a component (Tc) generally corresponds to the heat load of the heat dissipating components and therefore the subsystems contained in the racks **14***a*–**14***p*. Therefore, the Tc's may be based upon the temperatures of specific heat dissipating components and subsystems. In addition, the Tc's may be based upon the temperatures in the general vicinity of the racks and/or sections of the racks. Thus, those skilled in the art will understand that certain embodiments of the invention may be employed with the temperature sensors **312**–**326** located at various positions throughout the data center **10**. The number of temperature sensors and the temperature measurements of the number of racks may be upgradable, e.g., scalable, to include any additional components and/or racks that may be included in the data center. In addition, the temperature sensors need not be stationary. In this regard, according to another embodiment of the invention, a mobile device (not shown) is implemented to gather or measure at least one local environmental condition (e.g., temperature, air flow, humidity, etc.) in the data center **10**. More particularly, the mobile device is configured to travel around the racks to determine the one or more environmental conditions at various locations throughout the data center. In addition, the device may be configured to detect the one or more environmental conditions at various heights throughout the data center. The information gathered by the mobile device may be transmitted to the cooling system controller **332**. As described hereinabove, the cooling system controller **332** may vary the delivery and temperature of cooling fluid according to the one or more detected environmental conditions. In this respect, the energy necessary to cool the racks and the components contained therein, may substantially be optimized.

A more detailed description of the above-described embodiment may be found in co-pending U.S. application Ser. No. 10/157,892, filed May 31, 2002, which is assigned to the assignee of the present invention and is incorporated by reference herein in its entirety.

Moreover, use of the term "rack" herein generally refers additionally to sections of the racks and thus may not necessarily refer to an entire rack. Thus, the use of the term "rack" throughout the disclosure is not meant to limit certain aspects to entire racks, but instead, is implemented to simplify the description of certain embodiments of the invention.

At step **404**, the temperatures of the components (Tc's) are individually sensed by the temperature sensors **312**–**326**. Alternatively, the Tc's may be anticipated in the manner described hereinabove with respect to FIG. **3**A. At step **406**, it is determined whether each of the measured temperatures are individually within a predetermined range of operating temperatures, e.g., between a maximum and minimum

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ture (Tmax,set) and a minimum set point temperature (Tmin,set). The predetermined range of operating temperatures may be set according to a plurality of factors. These factors may include, for example, the operating temperatures set forth by the manufacturers of the subsystems and components located in the racks, through testing to determine the optimal operating temperatures, etc. In addition, the predetermined range of operating temperatures may vary from one subsystem to another on the basis that various subsystems generally may operate effectively at various temperatures.

The measured and/or anticipated temperatures for those racks determined to have heat loads that fall within the predetermined range of operating temperatures are sensed again at step **404**. For those racks determined to have heat loads that do not fall within the predetermined temperature range, i.e., fall outside of Tmin,set and Tmax,set, it is determined whether the sensed temperature equals or falls below the Tmin,set at step **408**. In general, the range of temperatures Tmin,set and Tmax,set pertain to threshold temperatures to determine whether to increase or decrease the flow of cooling fluid delivered to the racks. The predetermined temperature range may be based upon a plurality of factors, for example, a threshold operating range of temperatures that may be determined through testing to substantially optimize the performance of the subsystems contained in the racks. Moreover, the predetermined temperature range may vary for each rack because various components generally may operate effectively at various temperatures and thus various threshold temperatures may be optimal.

If the Tc's of some of the racks are below or equal to the Tmin,set, the CP controller **304** may operate to decrease the volume flow rate and/or the velocity of cooling fluid to those racks at step **410**. The determination of whether to decrease either or both the volume flow rate and the velocity of the cooling fluid may be based upon the detected temperatures of the racks. For example, if the subsystems on a bottom half of a rack are operating at 50 percent of maximum capacity, and the subsystems on an upper half of the rack are operating at or near zero capacity, the velocity of the cooling fluid may be reduced whereas the volume flow rate may remain substantially constant. This may occur, for example, because the cooling fluid need not travel a relatively long distance but may still need to supply the bottom half with a sufficient amount of cooling fluid.

If the Tc's of some of the racks exceed the Tmin,set (i.e., also exceed the Tmax,set), the CP controller **304** may operate to increase the volume flow rate and/or the velocity of cooling fluid to those racks at step **412**. The determination of whether to increase either or both the volume flow rate and the velocity of the cooling fluid may be based upon the detected temperature of the racks. For example, if the subsystems on the top half of a rack are operating at 100 percent capacity, and the subsystems on a bottom half of the rack are operating at or near zero capacity, the velocity and the volume flow rate of the cooling fluid may both be increased. This may occur, for example, because the cooling fluid must travel a relatively long distance and supply the top half with a sufficient amount of cooling fluid.

According to an embodiment of the invention, the decrease in volume flow rate and/or velocity of the cooling fluid flow at step **410** and the increase in volume and/or velocity of the cooling fluid at step **412** may be accomplished by incrementally varying the cooling fluid flow through the appropriate CPs. An example will be made for the instance where a CP allows a certain amount of cooling fluid to flow therethrough, and the CP is manipulated to decrease the volume flow rate of the cooling fluid, and where the decrease in fluid flow is insufficient to cause the Tc for the racks within that respective zone to fall within the predetermined range. In this instance, during a subsequent run through steps **304–310**, the CP may be controlled to further decrease the volume flow rate of the cooling fluid therethrough by an incremental amount. By repeating this process a number of times, the temperature of the racks within that respective zone may be substantially brought within the predetermined range.

At step **414**, the cooling system controller **332** may determine whether to decrease the cooling fluid output, e.g., decrease each compressor **44***a*–**44***d* speed and each fan **40***a*–**40***d* output. The determination of whether to decrease the cooling fluid output may be made in response to the manipulations made to the CPs **26***a*–**26***f* by the CP controller **304**. For instance, if the total amount of decreases in the volume flow rates of the cooling fluid exceeds the total amount of increases in the volume flow rates flow of the cooling fluid, the cooling system controller **332** may operate to decrease the cooling fluid output at step **416**. Alternatively, if the total amount of increases in the volume flow rates of the cooling fluid exceeds the total amount of decreases, the cooling system controller **332** may operate to increase the cooling system **302** output at step **418**.

Following steps **416** or **418**, or if the increases in the volume flow rates of the cooling fluid through the CPs **26***a*–**26***f* equals the decreases, for example, the Tc's are sensed again at step **404**. In addition, the steps following step **404** may be repeated for an indefinite period of time so long as the cooling system **302** is in operation.

It should be appreciated that the Tc's of some of the racks may fall below the Tmin,set, whereas the Tc's of other racks may exceed the Tmax,set. Thus, it should be appreciated that steps **410** and **412** may be respectively and substantially simultaneously performed on the various racks. In such an instance where the Tc of one rack in a zone exceeds the Tmax,set while the Tc of another rack in the same zone falls below the Tmin,set, the cooling requirements of relatively warmer rack may be utilized to control the flow of cooling fluid. However, it is within the scope of the invention that dynamically controllable vents be utilized to control the flow of cooling fluid to one rack or a subset thereof and thereby reduce the overall cooling requirements of a zone. A more detailed description of the above-described embodiment may be found in co-pending U.S. application Ser. No. 09/970,707, filed Oct. 5, 2001, which is assigned to the assignee of the present invention and is incorporated by reference herein in its entirety.

FIG. **4**B shows a flow diagram **450** of a manner in which another embodiment of the invention may be practiced. The following description of the flow diagram **450** is made with reference to the block diagram **350** illustrated in FIG. **3**B, and thus makes reference to the elements cited therein. It is to be understood that the steps illustrated in the flow diagram **450** may be contained as a utility, program, subprogram, in any desired computer accessible medium. In addition, the flow diagram **450** may be embodied by a computer program, which can exist in a variety of forms both active and inactive. For example, they can exist as software program(s) comprised of program instructions in source code, object code, executable code or other formats. Any of the above can be embodied on a computer readable medium, which include storage devices and signals, in compressed or uncompressed form.

Examples of computer readable storage devices include conventional computer system [illegible]

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memory), ROM (read only memory), EPROM (erasable, programmable ROM), EEPROM (electrically erasable, programmable ROM), and magnetic or optical disks or tapes. Examples of computer readable signals, whether modulated using a carrier or not, are signals that a computer system hosting or running the computer program can be configured to access, including signals downloaded through the Internet or other networks. Concrete examples of the foregoing include distribution of the programs on a CD ROM or via Internet download. In a sense, the Internet itself, as an abstract entity, is a computer readable medium. The same is true of computer networks in general. It is therefore to be understood that those functions enumerated below may be performed by any electronic device capable of executing the above-described functions.

In the flow diagram **450**, steps **452–462** respectively correspond to steps **402–412** recited hereinabove with respect to the flow diagram **400** illustrated in FIG. **4**A. Therefore, a detailed description of steps **452–462** will not be made herein. Instead, one of ordinary skill in the art will readily recognize that the description made hereinabove with respect to steps **402–412** has general applicability to steps **452–462** and may thus be used interchangeably.

Therefore, beginning at step **464**, the pressure of the cooling fluid supplying the zones **20***a*–**20***h* may be measured by the respective pressure sensors **56***a*–**56***h*. The measured pressure may be relayed to the cooling system controller **332**. The cooling system controller **332** may determine whether the measured pressure is within a predetermined pressure range, e.g., a predetermined minimum set point pressure (Pmin,set) and a predetermined maximum set point pressure (Pmax,set), at step **466**. The predetermined pressure range may be set according to a maximum desired volume flow rate and/or velocity of the cooling fluid to flow through the CPs **26***a*–**26***f*. In addition, the predetermined pressure range may be the substantial optimum operating pressure desired for controlling the flow of cooling fluid through each of the zones **20***a*–**20***h*. If the measured pressure is within the predetermined pressure range, the cooling system controller **332** returns to step **464**.

If the measured pressure is not within the predetermined pressure range, it is determined whether the measured pressure (P) is below or equal to a minimum pressure set point (Pmin,set) at step **468**. The pressure P is defined as the pressure difference between a location within the pressurized enclosure **18** and generally below a vent **24***a*–**24***h* and a location essentially above the respective vent **24***a*–**24***h*. In general, the predetermined pressure range pertains to the threshold pressures to determine whether to individually increase or decrease the supply of fluid, e.g., in each second chamber **54***a*–**54***h*. The predetermined pressure range may be based upon a plurality of factors, for example, a threshold operating pressure or range of pressures that may be determined through testing to substantially optimize the performance of the cooling fluid output through the CPs **26***a*–**26***f*.

If the P is determined to be below or equal to the Pmin,set, the cooling system controller **332** may operate to increase the cooling fluid output, e.g., by increasing the appropriate fan output, at step **470**. Otherwise, if the P is determined to exceed the Pmin,set, and thereby exceed the Pmax,set, the cooling system controller **332** may operate to decrease cooling fluid output, e.g., by decreasing the appropriate fan output, at step **472**.

Following steps **470** or **472**, the cooling system controller **332** returns to step **464**. In addition, the steps following step **464** may be repeated for an indefinite period of time so long as the cooling system **302** is in operation.

It should be appreciated that the Tc's of some of the zones and/or racks within some zones may fall below the Tmin,set, whereas the Tc's of other zones and/or racks within those zones may exceed the Tmax,set. Thus, in various embodiments of the invention, steps **460** and **462** may be respectively and substantially simultaneously performed on each the various zones and/or racks.

FIG. **5** shows a simplified schematic cross-sectional side view along lines IIA—IIA of FIG. **1** containing zones **20***g* and **20***h* in accordance with another embodiment of the invention. As shown in FIG. **5**, the data center **10** includes the cooling system **12***d* configured to receive cooling fluid through a pressurized enclosure **502** (e.g., plenum) located above a lowered ceiling **504**. This embodiment operates in a similar manner to the embodiments illustrated in FIGS. **1**, **2**A–**2**B, **3**A–**3**B, and **4**A–**4**B. The difference between the embodiment illustrated in FIG. **5** and those embodiments is that the cooling fluid heated by the components in the racks **14***a*–**14***p* is removed from above by returns **506***a*–**506***c*. In addition, the return flow of cooling fluid may be varied by the operation of a controllable partition ("CP") **508**. The CP **508** may be modulated by the operation of a motor **510** in a manner similar to the CP **26***a*–**26***f* discussed above. In this manner, relatively warm air may be removed more efficiently. A more detailed description of the above-described embodiment may be found in co-pending U.S. application Ser. No. Not Yet Assigned, filed Oct. 3, 2002, which is assigned to the assignee of the present invention and is incorporated by reference herein in its entirety.

It should be understood that the vents **24***a*–**24***h* operate to supply cooling fluid to the racks **14***a*–**14***p* in much the same manner as that described hereinabove with respect to FIGS. **1**, **2**A–**2**B, **3**A–**3**B, and **4**A–**4**B. Therefore, the description set forth hereinabove with respect to the above-described embodiments are relied upon to provide a description of the embodiment illustrated in FIG. **5**.

In accordance with an embodiment of the invention, the cooling requirements within a data center may be analyzed to substantially optimize the layout of the racks within zones of the data center. In one respect, the substantial optimization of the rack layout in the data center may enable the cooling system of the data center to operate at generally lower energy and greater efficiency levels by virtue of the reduced workload placed on the components of the cooling systems, e.g., compressors, fans, etc. The cooling requirements within the data center may be analyzed by operation of any reasonably suitable commercially available computational fluid dynamics (CFD) tool, e.g., FLOVENT, a 3-D modeling software capable of predicting temperature variations based upon fluid flows. By virtue of the numerical modeling, various air conditioning units as well as the vents described hereinabove may be positioned throughout the data center to substantially control the manner in which the racks receive the cooling fluid. In addition, the air conditioning units may also be positioned to substantially maximize and optimize their performances, e.g., to prevent one or more of the air conditioning units from being overworked.

In determining the cooling fluid distribution requirement within the data center, each of the racks may be assigned a heat load which may correspond to a maximum heat load predicted for that rack, e.g., through anticipated power draw. For example, a rack containing 40 subsystems, e.g., computers, may have a maximum heat load of 10 KW and a rack containing 20 subsystems may have a maximum heat load of 5 KW. By implementing the CFD in this manner, for example in a data center containing 100 racks and four air conditioning units, racks having a [illegible]

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larger heat loads may be relatively separately located throughout the data center. In one respect, therefore, the air conditioning units within the data center may be operated at substantially legs than maximum power levels and the racks may receive sufficient amounts of cooling fluid. More specifically, the power required to operate the air conditioning units may be regulated to efficiently cool the fluid supplied to the racks by providing substantially only that amount of cooling fluid necessary to maintain the racks within normal operating temperatures.

According to another embodiment of the invention, a CFD tool may be implemented substantially continuously with the embodiments described hereinabove with respect to FIGS. **1–5**. More specifically, the CFD tool may be utilized to substantially continuously vary the operation of the cooling system to operate according to the heat loads generated in the racks. In this regard, the anticipated or actual heat loads (e.g., based upon the power draw of the components) on the racks may be inputted into the CFD tool, along with one or more of the following properties: velocity of the cooling fluid flowing through various sections of the data center and the distribution of temperature and pressure of the cooling fluid in the data center, to determine an optimal manner in which the air conditioning units may be operated as well as the flow of the cooling fluid through the CPs to adequately cool the racks within each zone based upon an analysis of the data center layout and the heat loads. The CFD tool may be implemented to produce a numerical model of the data center to thus determine an optimized cooling distribution within the data center. A correlation of one or more of the following properties: velocity of the cooling fluid flowing through various zones of the data center, distribution of temperature and pressure of the cooling fluid in the data center, and the power draw into the racks, may be created based on the numerical modeling. The correlation may be used to infer thermal conditions throughout the data center when only a minimum number of sensors are available during operation of the cooling system. In addition, the correlation may substantially reduce the amount of time required for the CFD tool to perform the computing operations.

Thus, for example, with respect to FIG. **4A**, at step **412**, a numerical model may be created to analyze an optimal manner in which the volume flow and/or the velocity of the cooling fluid may be increased while considering the effects of fluid flow from other racks. In this respect, based upon the analysis, the CP supplying the respective zone and/or the vent supplying that rack with cooling fluid and/or another CP and/or vent may be caused to vary the volume flow and/or velocity of the cooling fluid. In addition, at step **414**, the numerical model may be created to determine whether the cooling system output should be decreased based upon the heat loads and the fluid flow throughout the data center. For example, if it is determined that a rack with an increasing heat load may receive a sufficient amount of cooling fluid by receiving cooling fluid from a vent in another zone or generally away therefrom, the cooling system output may not be increased. Furthermore, the CFD tool may be utilized to analyze fluid flow characteristics in a situation in which a zone without a cooling system (e.g., zones **20***b*, **20***d*, **20***e*, and **20***f*) is generating a relatively greater amount of heat than adjacent zones.

In such a situation, the analysis may indicate a subset of the processing load be transferred. Alternatively or in addition, one or more vents within zones having a cooling system (e.g., zones **20***a*, **20***c*, **20***f*, and **20***h*) may be controlled to reduce the flow of fluid therethrough and thus, increase the available flow to zones in fluid communication. In this regard, as described generally hereinabove and in more detail within co-pending U.S. application Ser. No. 09/970,707, filed Oct. 5, 2001, which is assigned to the assignee of the present invention and is incorporated by reference herein in its entirety, the vents **24***a–24h* may be dynamically controllable.

Moreover, it is within the scope of the invention that a fan (not shown) in or near a CP **26***a–26f* be controlled to increase the flow of cooling fluid through an associated CP **26***a–26f*. Thus, by implementation of the CFD tool to generally analyze the fluid flow characteristics and the temperatures of the racks, the amount of energy required to sufficiently cool the racks within each of the zones in the data center may be substantially optimized.

By virtue of certain aspects of the invention, one of ordinary skill in the art will readily recognize that the amount of energy, and thus the costs associated with cooling the racks located within a data center may be substantially reduced. In one respect, by operating the cooling system to supply cooling fluid substantially only as needed by each respective zone, the cooling system may be operated at a relatively more efficient manner as compared to conventional cooling systems.

What has been described and illustrated herein is an embodiment of the invention along with some of its variations. The terms, descriptions and figures used herein are set forth by way of illustration only and are not meant as limitations. Those skilled in the art will recognize that many variations are possible within the spirit and scope of the invention, which is intended to be defined by the following claims—and their equivalents—in which all terms are meant in their broadest reasonable sense unless otherwise indicated.

What is claimed is:

1. A method of cooling a plurality of racks in a data center, said method comprising:

activating a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks;

sensing the temperature of said at least one associated rack;

determining whether said sensed temperature is within a predetermined temperature range; and

manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to said sensed temperature being outside said predetermined temperature range.

2. The method according to claim **1**, further comprising:

determining whether the measured temperature of said at least one associated rack is below or equal to a predetermined minimum set point temperature; and

decreasing the supply of said cooling fluid to said zone in response to said at least one associated rack having a measured temperature that falls below or equal said predetermined minimum set point temperature.

3. The method according to claim **1**, further comprising:

sensing a pressure of a supply of said cooling fluid;

determining whether said sensed pressure is within a predetermined pressure range; and

varying an output of said cooling device in response to said sensed pressure falling outside of said predetermined pressure range.

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4. The method according to claim 2, further comprising:

increasing the supply of said cooling fluid to said zone in response to said at least one associated rack having a measured temperature that exceed said predetermined minimum set point temperature.

5. The method according to claim 3, wherein said step of varying said cooling device output includes determining whether said measured pressure falls below or equals a predetermined minimum set point pressure.

6. The method according to claim 4, further comprising:

decreasing an output of said cooling fluid from said cooling device in response to said decrease in cooling fluid supply to said zone exceeding said increase in cooling fluid supply to said zone.

7. The method according to claim 4, further comprising:

opening a plurality of vents, said vents being configured to supply cooling fluid to said racks;

controlling one or more of said plurality vents to decrease the supply of said cooling fluid to said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature; and

controlling said one or more vents to increase the supply of said cooling fluid to said at least one associated rack having a measured temperature that exceed said predetermined minimum set point temperature.

8. The method according to claim 4, further comprising:

opening a plurality of returns, said returns being configured to remove cooling fluid from various locations of said data center; and

controlling one or more of said plurality of returns to decrease the removal of said cooling fluid from around said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature; and

controlling said one or more returns to increase the removal of said cooling fluid from around said at least one associated rack having a measured temperature that exceed said predetermined minimum set point temperature.

9. The method according to claim 4, further comprising:

receiving temperatures from a movable device configured to detect at least one environmental condition at various locations of said data center;

determining whether at least one of said sensed temperatures and received temperatures are within a predetermined temperature range; and

manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to at least one of said sensed and received temperatures being outside of said predetermined temperature range.

10. The method according to claim 4, further comprising:

performing a numerical modeling of a temperature distribution and flow characteristics of the data center; and

manipulating said cooling device in response to said numerical modeling.

11. The method according to claim 5, further comprising:

increasing the output of said cooling device in response to said measured pressure falling below or equaling said predetermined minimum set point pressure.

12. The method according to claim 5, further comprising:

decreasing the output of said cooling device in response to said measured pressure exceeding said predetermined minimum set point pressure.

13. The method according to claim 6, further comprising:

increasing an output of said cooling fluid from said cooling device in response to said decrease in cooling fluid supply to said zone falling below said increase in cooling fluid supply to said zone.

14. The method according to claim 7, further comprising:

determining whether said at least one associated rack having a measured temperature that exceeds said predetermined minimum set point temperature is relatively downstream of the supply of said cooling fluid from said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature; and

controlling said one or more vents to decrease the supply of said cooling fluid to said at least one associated rack being relatively upstream of the supply of said cooling fluid and controlling said one or more vents to increase the supply of said cooling fluid to said at least one associated rack being relatively downstream of the supply of said cooling fluid in response to determining said at least one associated rack having a measured temperature that exceeds said predetermined minimum set point temperature is relatively downstream of the supply of said cooling fluid from said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature.

15. The method according to claim 10, further comprising:

implementing said numerical modeling to correlate at least two of temperature, velocity and pressure of said cooling fluid and power draw of at least one of said zone and said racks within said data center to thereby infer a thermal condition throughout said data center, wherein said manipulating step further comprises manipulating said cooling device in response to said inferred thermal condition.

16. A apparatus of cooling a plurality of racks in a data center, said apparatus comprising:

means for activating a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks;

means for sensing the temperature of said at least one associated rack;

means for determining whether said sensed temperature is within a predetermined temperature range; and

means for manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to said sensed temperature being outside said predetermined temperature range.

17. The apparatus according to claim 16, further comprising:

means for determining whether the measured temperature of said at least one associated rack is below or equal to a predetermined minimum set point temperature;

means for decreasing the supply of said cooling fluid to said zone in response to said at least one associated rack having a measured temperature that falls below or equal said predetermined minimum set point temperature; and

means for increasing the supply of said cooling fluid to said zone in response to said at least one associated rack having a measured temperature that exceed said predetermined minimum set point temperature.

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18. The apparatus according to claim 16, further comprising:

means for sensing a pressure of a supply of said cooling fluid;

means for determining whether said sensed pressure is within a predetermined pressure range; and

means for varying an output of said cooling device in response to said sensed pressure falling outside of said predetermined pressure range, wherein said step of varying said cooling device output includes determining whether said measured pressure falls below or equals a predetermined minimum set point pressure.

19. The apparatus according to claim 17, further comprising:

decreasing an output of said cooling fluid from said cooling device in response to said decrease in cooling fluid supply to said zone exceeding said increase in cooling fluid supply to said zone; and

means for increasing an output of said cooling fluid from said cooling device in response to said decrease in cooling fluid supply to said zone falling below said increase in cooling fluid supply to said zone.

20. The apparatus according to claim 17, further comprising:

means for opening a plurality of vents, said vents being configured to supply cooling fluid to said racks;

means for controlling one or more of said plurality vents to decrease the supply of said cooling fluid to said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature; and

means for controlling said one or more vents to increase the supply of said cooling fluid to said at least one associated rack having a measured temperature that exceed said predetermined minimum set point temperature.

21. The apparatus according to claim 17, further comprising:

means for opening a plurality of returns, said returns being configured to remove cooling fluid from various locations of said data center; and

means for controlling one or more of said plurality of returns to decrease the removal of said cooling fluid from around said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature; and

means for controlling said one or more returns to increase the removal of said cooling fluid from around said at least one associated rack having a measured temperature that exceed said predetermined minimum set point temperature.

22. The apparatus according to claim 17, further comprising:

means for receiving temperatures from a movable device configured to detect at least one environmental condition at various locations of said data center;

means for determining whether at least one of said sensed temperatures and received temperatures are within a predetermined temperature range; and

means for manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to at least one of said sensed and received temperatures being outside of said predetermined temperature range.

23. The apparatus according to claim 17, further comprising:

means for performing a numerical modeling of a temperature distribution and flow characteristics of the data center; and

means for manipulating said cooling device in response to said numerical modeling.

24. The apparatus according to claim 18, further comprising:

means for increasing the output of said cooling device in response to said measured pressure falling below or equaling said predetermined minimum set point pressure; and

means for decreasing the output of said cooling device in response to said measured pressure exceeding said predetermined minimum set point pressure.

25. The apparatus according to claim 20, further comprising:

means for determining whether said at least one associated rack having a measured temperature that exceeds said predetermined minimum set point temperature is relatively downstream of the supply of said cooling fluid from said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature; and

means for controlling said one or more vents to decrease the supply of said cooling fluid to said at least one associated rack being relatively upstream of the supply of said cooling fluid and controlling said one or more vents to increase the supply of said cooling fluid to said at least one associated rack being relatively downstream of the supply of said cooling fluid in response to determining said at least one associated rack having a measured temperature that exceeds said predetermined minimum set point temperature is relatively downstream of the supply of said cooling fluid from said at least one associated rack having a measured temperature that fall below or equal said predetermined minimum set point temperature.

26. The apparatus according to claim 23, further comprising:

means for implementing said numerical modeling to correlate at least two of temperature, velocity and pressure of said cooling fluid and power draw of at least one of said zone and said racks within said data center to thereby infer a thermal condition throughout said data center, wherein said manipulating step further comprises manipulating said cooling device in response to said inferred thermal condition.

27. A cooling system for cooling racks in a data center, said system comprising:

a cooling device for supplying cooling fluid to said racks, said cooling device including a fan;

a plenum for conveying said cooling fluid to said racks, said plenum being in fluid communication with said fan; and

a controllable partition located within said plenum, wherein pressure of said cooling fluid in said plenum is controlled by modulation of said partition.

28. The system according to claim 27, wherein said plenum includes a divider operable to divide said plenum into a first chamber and a second chamber, wherein said first chamber is in fluid communication with said cooling device and at least one of said first chamber and said second chamber is in fluid communication with said controllable partition, and wherein said divider operates to maintain the pressure of said cooling fluid in said second chamber at a substantially uniform pressure.

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29. The system according to claim 27, wherein said controllable partition is comprised of a plurality of louvers operable to adjust from fully open to fully closed.

30. The system according to claim 27, wherein said controllable partition is operable to rotate.

31. The system according to claim 27, wherein said controllable partition is operable to retract and elongate.

32. The system according to claim 27, further comprising:

a return plenum having a plurality of returns and an outlet, wherein said outlet of said return plenum is in fluid communication with said fan, wherein said plurality of returns are configured for removing said cooling fluid from said data center and are operable to vary a characteristic of said removal of cooling fluid through said returns; and

at least one return controller operable to control at least one of said returns, wherein said at least one return controller is configured to substantially independently control said returns to thereby substantially independently vary said characteristic of said cooling fluid removal.

33. The system according to claim 27, further comprising:

a plurality of vents for delivering said cooling fluid to said racks, wherein said vents are operable to vary a characteristic of said cooling fluid delivered through each of said vents; and

at least one vent controller operable to control at least one of said vents, wherein said at least one vent controller is configured to independently control said vents to thereby independently vary said characteristic of said cooling fluid.

34. The system according to claim 27, further comprising:

a baffle positioned within said plenum for generating substantially laminar flow of said cooling fluid.

35. The system according to claim 27, further comprising a sensor for measuring an environmental condition, wherein a characteristic of said supply of cooling fluid is modified in response to said measured environmental condition, said characteristic of said cooling fluid including at least one of volume flow rate and velocity, and said environmental condition including at least one of temperature, pressure, air flow, and humidity.

36. The system according to claim 34, wherein said baffle is further configured to control the direction of flow of said cooling fluid and the system further comprises:

a controller operable to control said baffle, wherein said controller is configured to control said baffle to vary the direction of flow of said cooling fluid.

37. The system according to claim 35, further comprising:

a plurality of controllable partitions configured to subdivide said plenum into a plurality of zones; and

at least one controllable partition controller operable to control at least one of said controllable partitions, wherein said at least one controllable partition controller is configured to independently control said controllable partitions to thereby independently vary said characteristic of said cooling fluid.

38. The system according to claim 37, wherein said sensor comprises a plurality of sensors configured to measure said environmental condition of said racks and said at least one controllable partition controller is configured to independently control said controllable partitions in response to said measured environmental condition at each of said racks.

39. The system according to claim 37, wherein said at least one controllable partition controller is operable to independently control each of said controllable partitions on the basis of an anticipated amount of heat predicted to be generated by each of said racks.

40. The system according to claim 37, further comprising:

a cooling device controller operable to control said supply of cooling fluid from said cooling device in response to signals received from said at least one controllable partition controller and thereby vary the cooling fluid supply in said plenum.

41. The system according to claim 37, further comprising a mobile device having said sensor and configured to navigate said data center and relay data associated with said environmental conditions to said at least one controllable partition controller.

* * * * *

EXHIBIT D

US007031870B2

(12) **United States Patent**
Sharma et al.

(10) **Patent No.: US 7,031,870 B2**
(45) **Date of Patent: Apr. 18, 2006**

(54) **DATA CENTER EVALUATION USING AN AIR RE-CIRCULATION INDEX**

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(73) Assignee: **Hewlett-Packard Development Company, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 126 days.

(21) Appl. No.: **10/855,400**

(22) Filed: **May 28, 2004**

(65) **Prior Publication Data**

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G01K 1/00 (2006.01)
G01K 11/00 (2006.01)

(52) **U.S. Cl.** **702/130**

(58) **Field of Classification Search** 702/130
See application file for complete search history.

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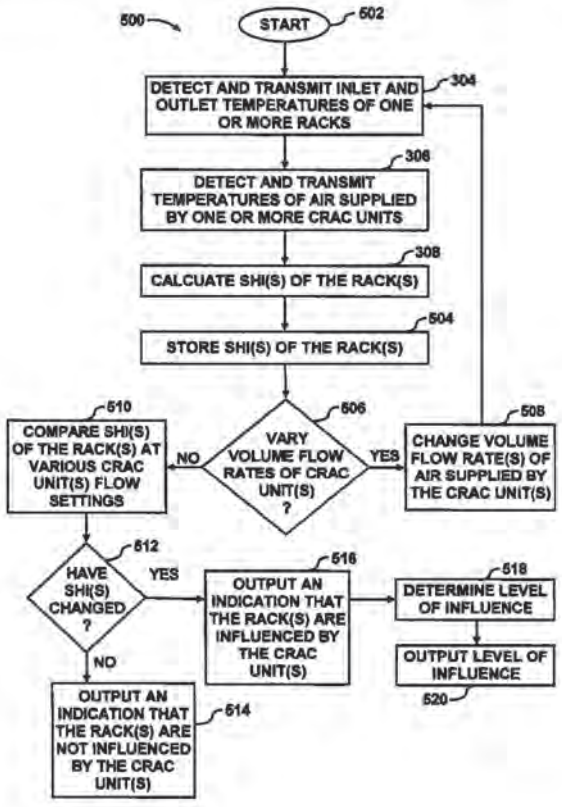
* cited by examiner

Primary Examiner—John Barlow
Assistant Examiner—Demetrius R. Pretlow
(74) *Attorney, Agent, or Firm*—Richard P. Lange

(57) **ABSTRACT**

In a method for evaluating one or more components in a data center, inlet and outlet temperatures of one or more heat dissipating devices are detected. In addition, the temperatures of air supplied by one or more computer room air conditioning (CRAC) units are also detected. Indices of air re-circulation for the one or more heat dissipating devices are calculated based upon the detected inlet temperatures, outlet temperatures and supplied air temperatures. The indices of air re-circulation are determined at various flow field settings of air delivered to the one or more heat dissipating devices and the one or more components are evaluated based upon changes in the indices of air re-circulation for the one or more heat dissipating devices at the various flow field settings.

41 Claims, 9 Drawing Sheets



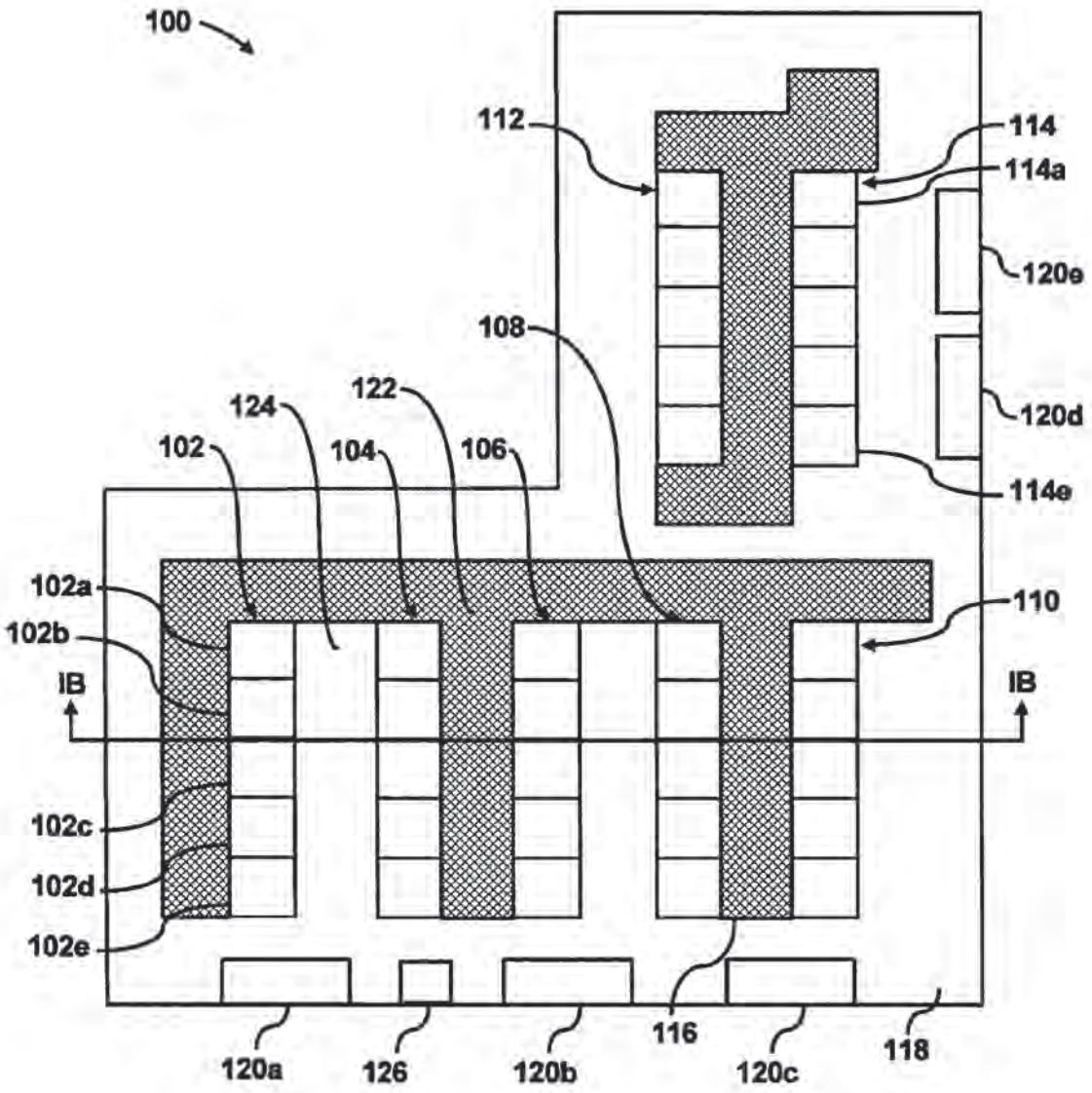

100
112
114
114a
120e
108
122
124
102
104
106
120d
114e
102a
102b
110
IB
IB
102c
102d
102e
116
118
120a
126
120b
120c

FIG. 1A

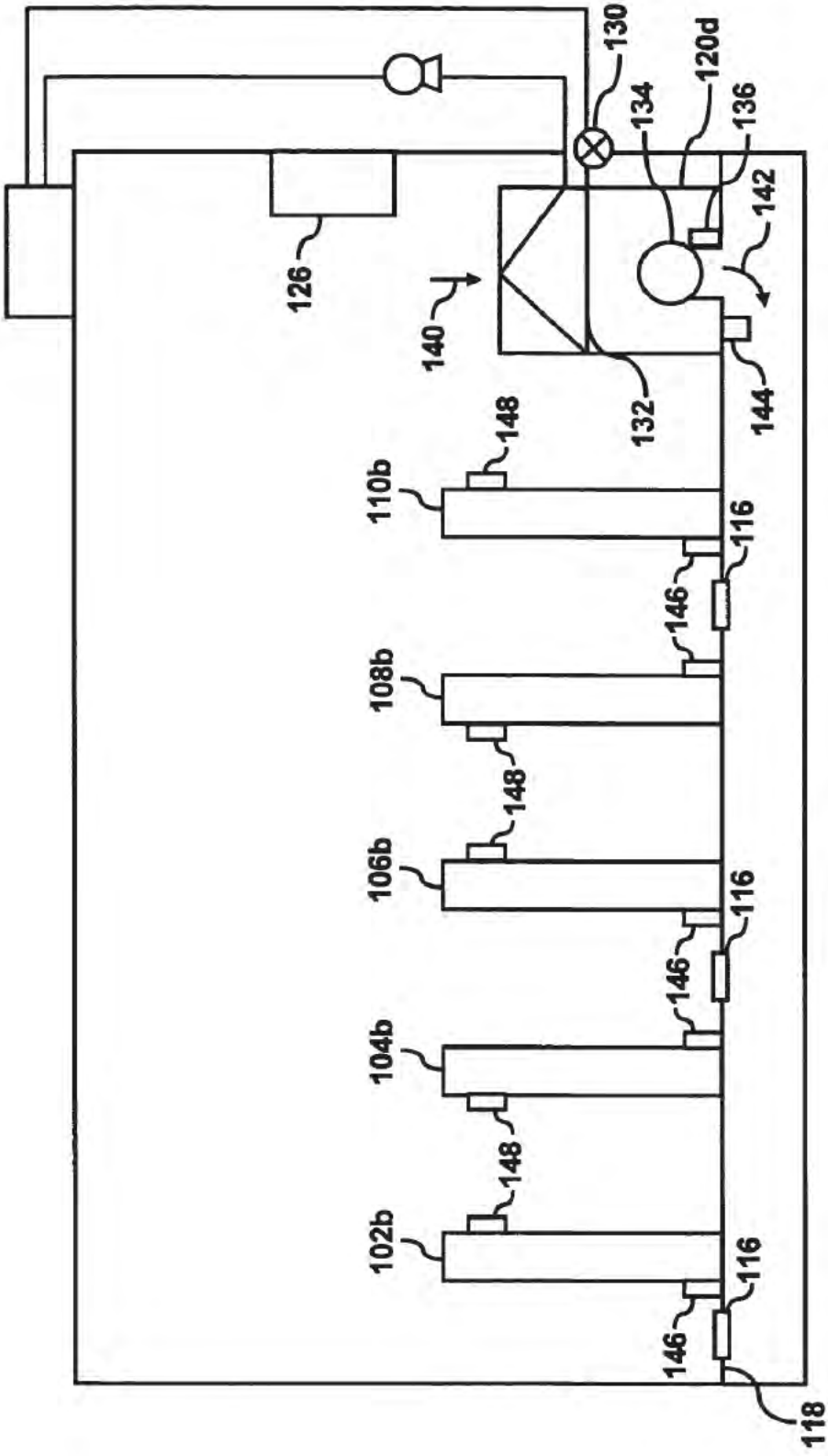

130
120d
134
136
142
126
140
132
144
148
110b
116
146
108b
148
106b
116
146
104b
148
102b
116
146
118

FIG. 1B

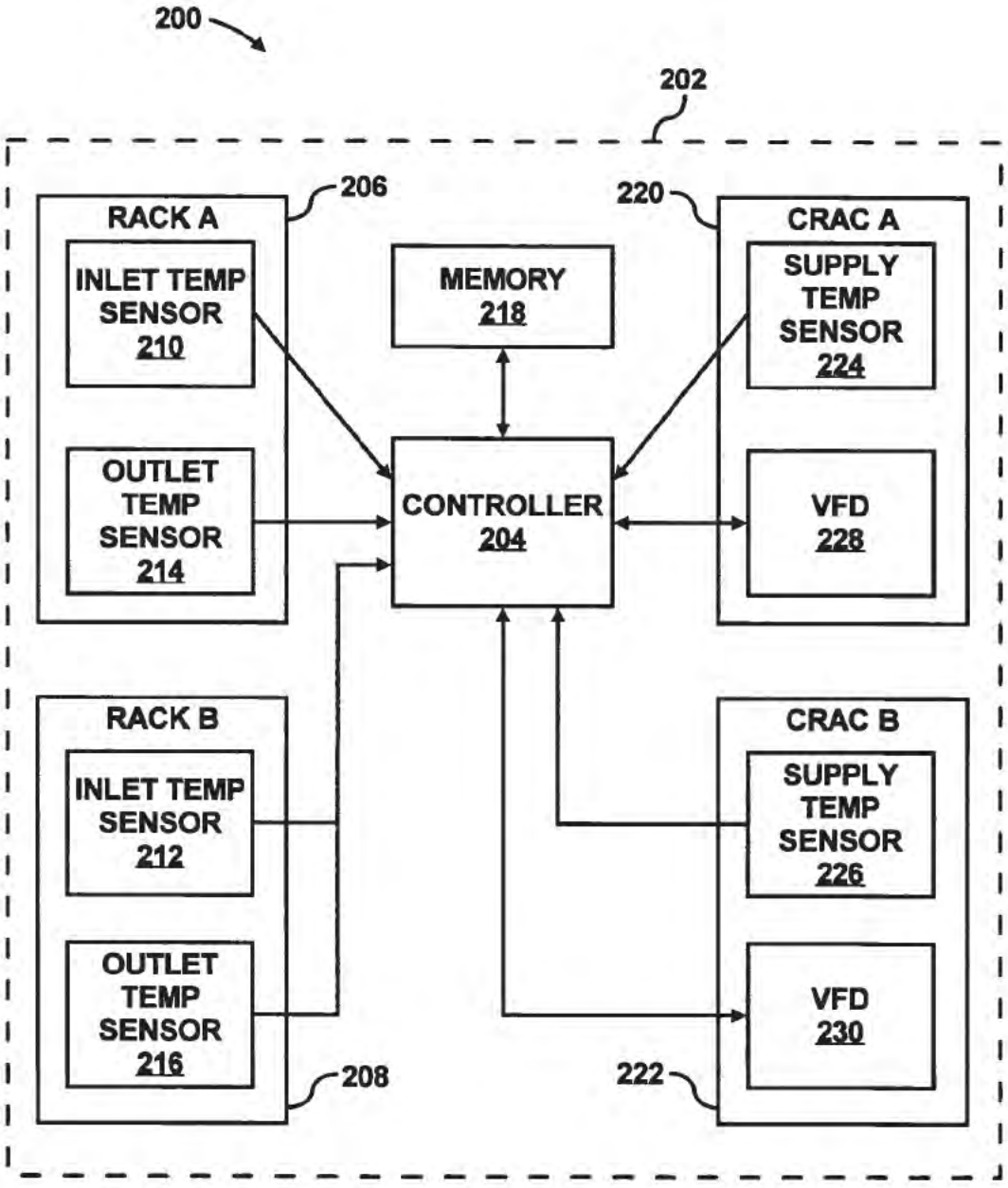

200
202
206
RACK A
INLET TEMP SENSOR 210
OUTLET TEMP SENSOR 214
MEMORY 218
CONTROLLER 204
220
CRAC A
SUPPLY TEMP SENSOR 224
VFD 228
RACK B
INLET TEMP SENSOR 212
OUTLET TEMP SENSOR 216
208
CRAC B
SUPPLY TEMP SENSOR 226
VFD 230
222

FIG. 2

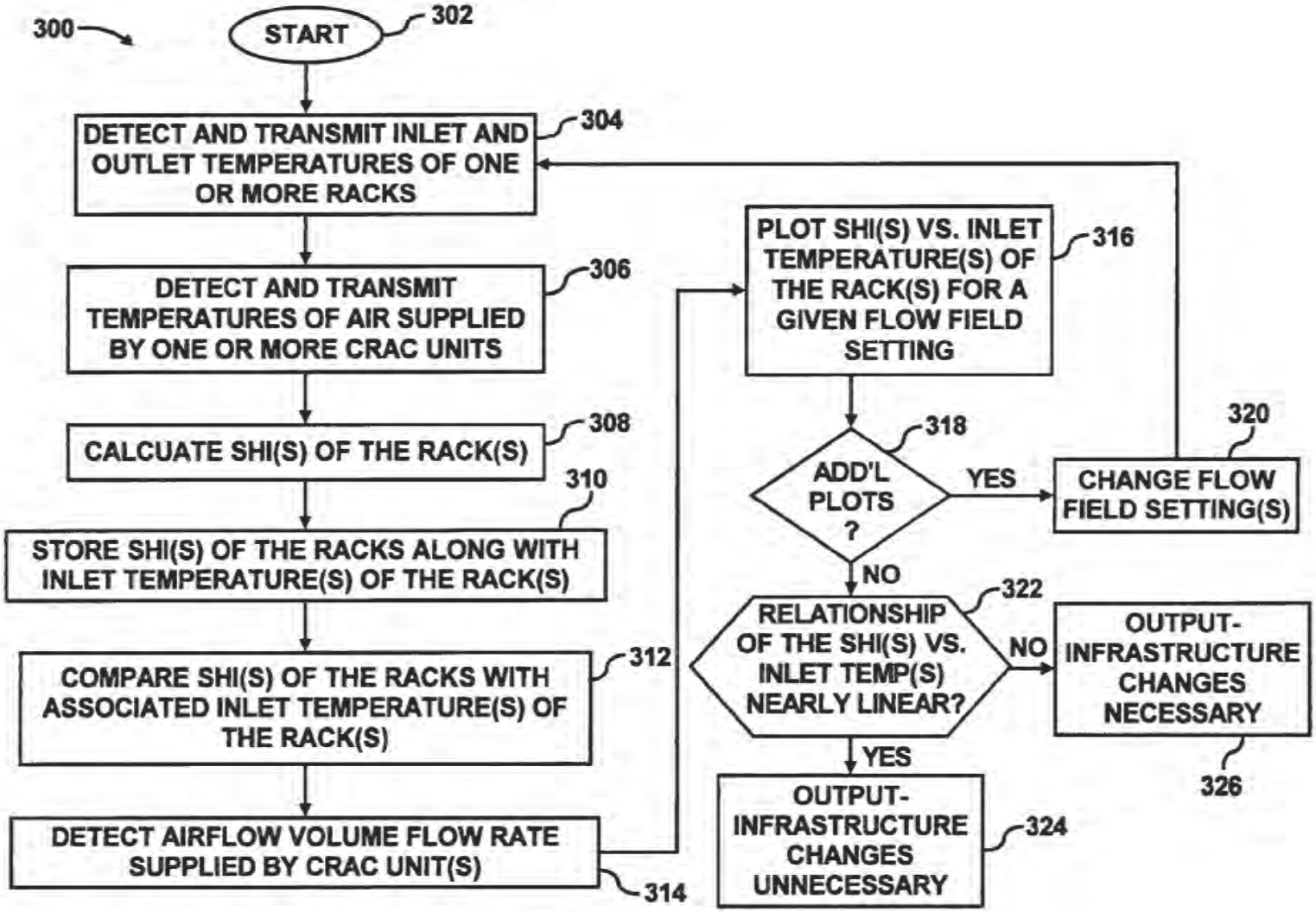

300
START
302
DETECT AND TRANSMIT INLET AND OUTLET TEMPERATURES OF ONE OR MORE RACKS
304
DETECT AND TRANSMIT TEMPERATURES OF AIR SUPPLIED BY ONE OR MORE CRAC UNITS
306
CALCUATE SHI(S) OF THE RACK(S)
308
STORE SHI(S) OF THE RACKS ALONG WITH INLET TEMPERATURE(S) OF THE RACK(S)
310
COMPARE SHI(S) OF THE RACKS WITH ASSOCIATED INLET TEMPERATURE(S) OF THE RACK(S)
312
DETECT AIRFLOW VOLUME FLOW RATE SUPPLIED BY CRAC UNIT(S)
314
PLOT SHI(S) VS. INLET TEMPERATURE(S) OF THE RACK(S) FOR A GIVEN FLOW FIELD SETTING
316
ADD'L PLOTS ?
318
YES
CHANGE FLOW FIELD SETTING(S)
320
NO
RELATIONSHIP OF THE SHI(S) VS. INLET TEMP(S) NEARLY LINEAR?
322
NO
OUTPUT-INFRASTRUCTURE CHANGES NECESSARY
326
YES
OUTPUT-INFRASTRUCTURE CHANGES UNNECESSARY
324

FIG. 3

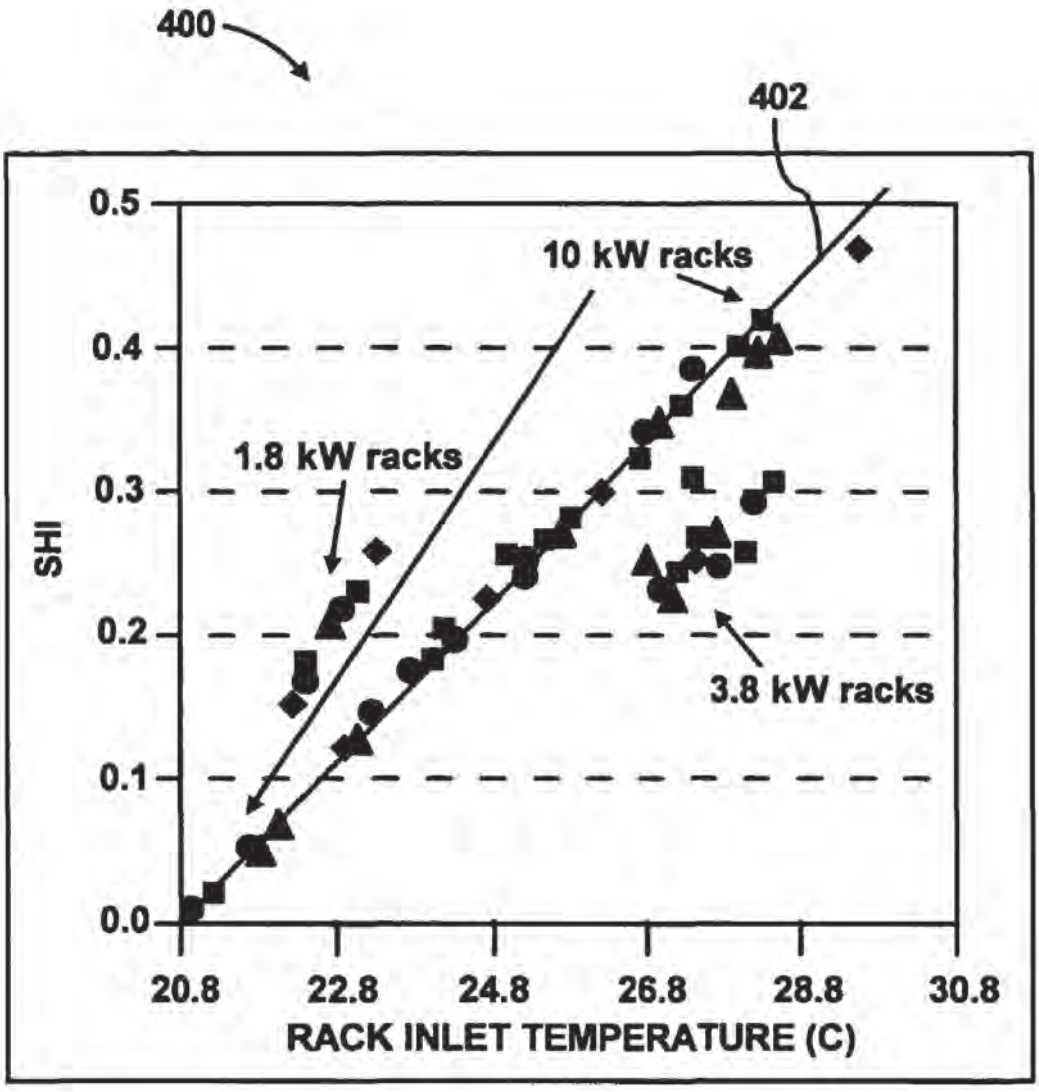

400
402
0.5
0.4
0.3
0.2
0.1
0.0
SHI
10 kW racks
1.8 kW racks
3.8 kW racks
20.8
22.8
24.8
26.8
28.8
30.8
RACK INLET TEMPERATURE (C)

FIG. 4A

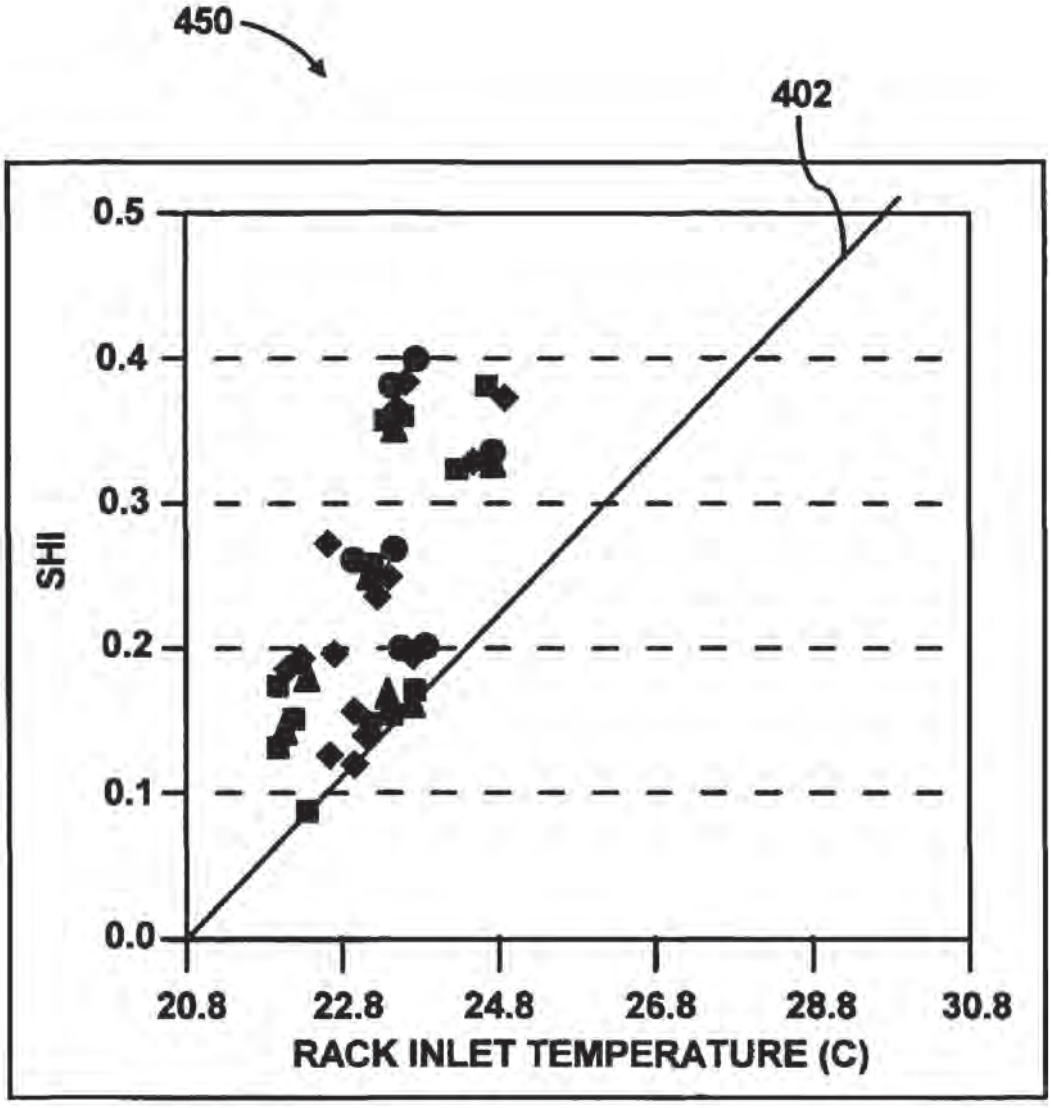

450
402
0.5
0.4
0.3
0.2
0.1
0.0
SHI
20.8
22.8
24.8
26.8
28.8
30.8
RACK INLET TEMPERATURE (C)

FIG. 4B

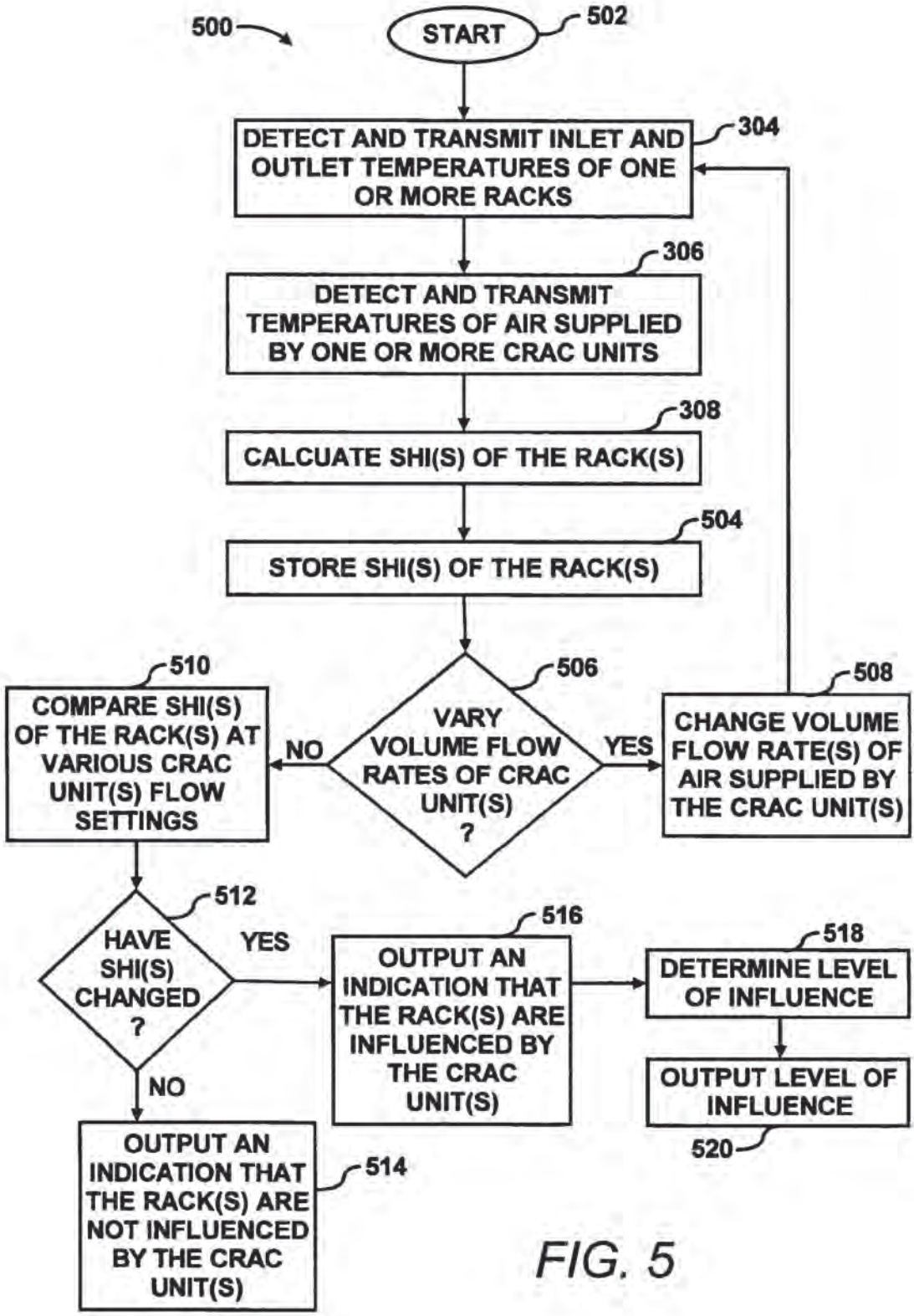

500
START
502
DETECT AND TRANSMIT INLET AND OUTLET TEMPERATURES OF ONE OR MORE RACKS
304
DETECT AND TRANSMIT TEMPERATURES OF AIR SUPPLIED BY ONE OR MORE CRAC UNITS
306
CALCUATE SHI(S) OF THE RACK(S)
308
STORE SHI(S) OF THE RACK(S)
504
VARY VOLUME FLOW RATES OF CRAC UNIT(S) ?
506
NO
YES
CHANGE VOLUME FLOW RATE(S) OF AIR SUPPLIED BY THE CRAC UNIT(S)
508
COMPARE SHI(S) OF THE RACK(S) AT VARIOUS CRAC UNIT(S) FLOW SETTINGS
510
HAVE SHI(S) CHANGED ?
512
YES
NO
OUTPUT AN INDICATION THAT THE RACK(S) ARE INFLUENCED BY THE CRAC UNIT(S)
516
DETERMINE LEVEL OF INFLUENCE
518
OUTPUT LEVEL OF INFLUENCE
520
OUTPUT AN INDICATION THAT THE RACK(S) ARE NOT INFLUENCED BY THE CRAC UNIT(S)
514

FIG. 5

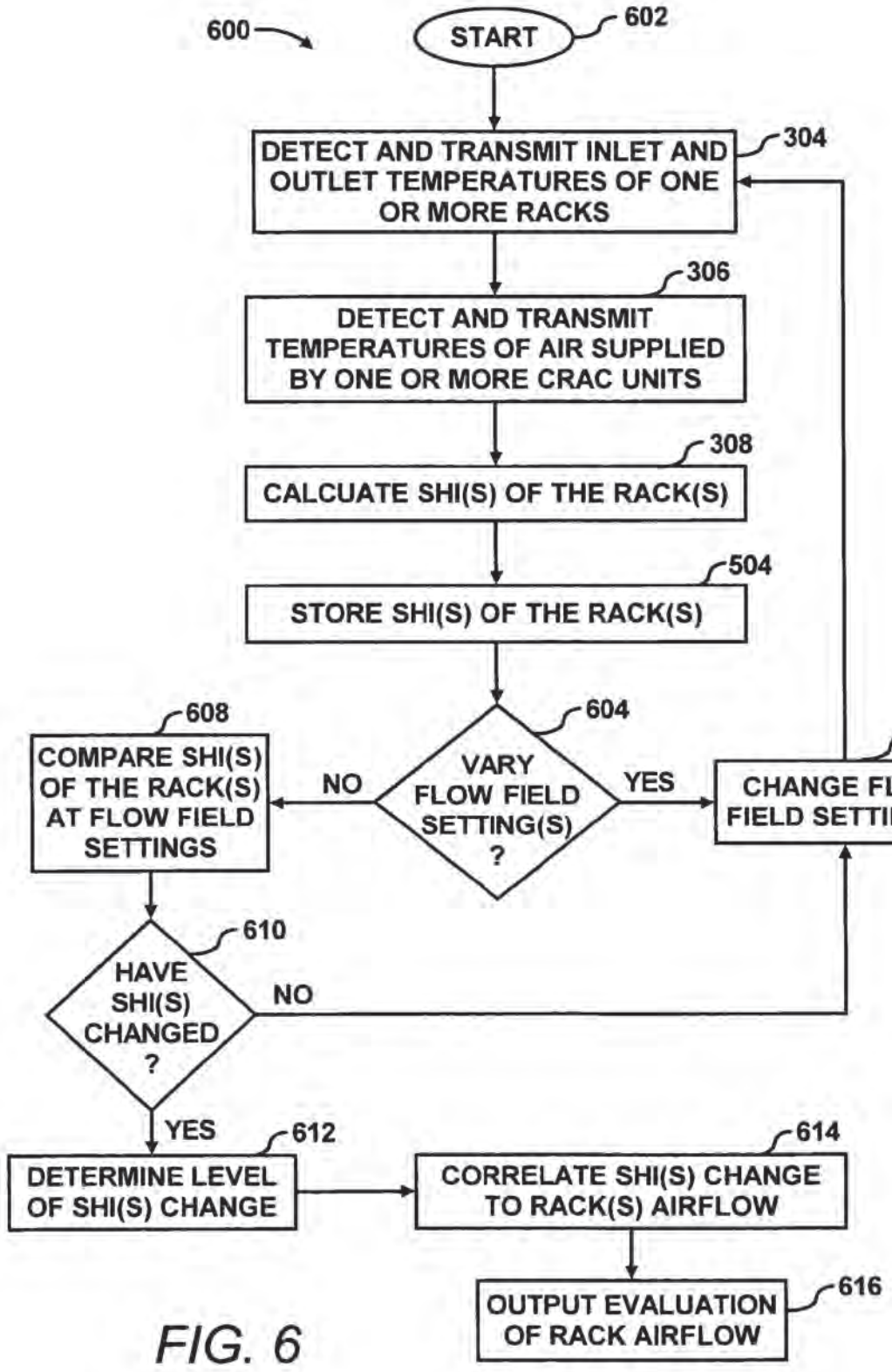

600
START
602
DETECT AND TRANSMIT INLET AND OUTLET TEMPERATURES OF ONE OR MORE RACKS
304
DETECT AND TRANSMIT TEMPERATURES OF AIR SUPPLIED BY ONE OR MORE CRAC UNITS
306
CALCUATE SHI(S) OF THE RACK(S)
308
STORE SHI(S) OF THE RACK(S)
504
VARY FLOW FIELD SETTING(S) ?
604
NO
YES
COMPARE SHI(S) OF THE RACK(S) AT FLOW FIELD SETTINGS
608
CHANGE FLOW FIELD SETTING(S)
606
HAVE SHI(S) CHANGED ?
610
NO
YES
DETERMINE LEVEL OF SHI(S) CHANGE
612
CORRELATE SHI(S) CHANGE TO RACK(S) AIRFLOW
614
OUTPUT EVALUATION OF RACK AIRFLOW
616

FIG. 6

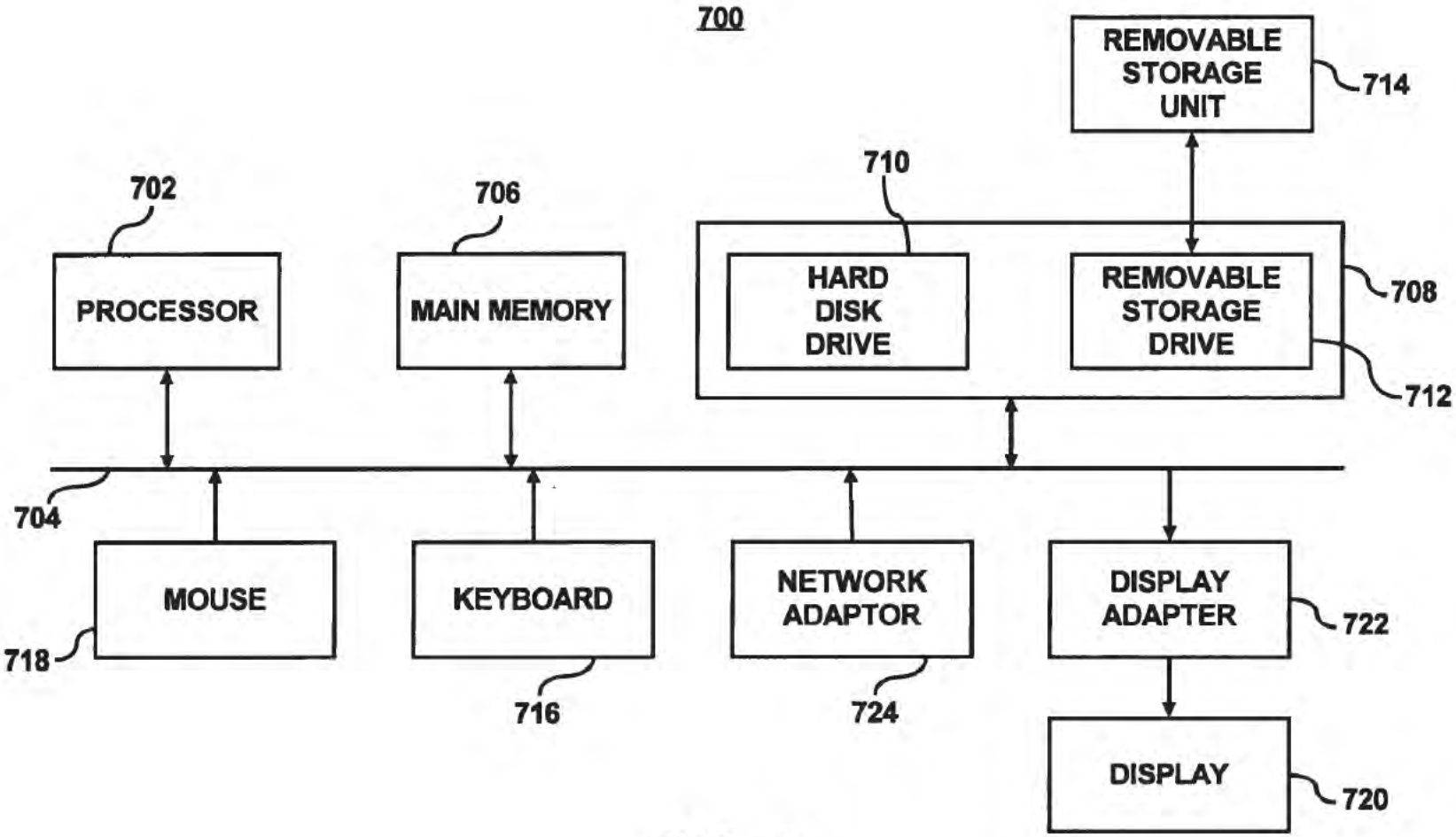

700
REMOVABLE STORAGE UNIT
714
710
702
706
PROCESSOR
MAIN MEMORY
HARD DISK DRIVE
REMOVABLE STORAGE DRIVE
708
712
704
MOUSE
KEYBOARD
NETWORK ADAPTOR
DISPLAY ADAPTER
722
718
716
724
DISPLAY
720

FIG. 7

DATA CENTER EVALUATION USING AN AIR RE-CIRCULATION INDEX

BACKGROUND OF THE INVENTION

A data center may be defined as a location, for instance, a room, that houses computer systems arranged in a number of racks. A standard rack, for example, an electronics cabinet, is defined as an Electronics Industry Association (EIA) enclosure, 78 in. (2 meters) high, 24 in. (0.61 meter) wide and 30 in. (0.76 meter) deep. These racks are configured to house a number of computer systems, about forty (40) systems, with future configurations of racks being designed to accommodate 200 or more systems. The computer systems typically include a number of printed circuit boards (PCBs), mass storage devices, power supplies, processors, micro-controllers, and semi-conductor devices, that dissipate relatively significant amounts of heat during their operation. For example, a typical computer system comprising multiple microprocessors dissipates approximately 250 W of power. Thus, a rack containing forty (40) computer systems of this type dissipates approximately 10 KW of power.

The power required to transfer the heat dissipated by the components in the racks to the cool air contained in the data center is generally equal to about 10 percent of the power needed to operate the components. However, the power required to remove the heat dissipated by a plurality of racks in a data center is generally equal to about 50 percent of the power needed to operate the components in the racks. The disparity in the amount of power required to dissipate the various heat loads between racks and data centers stems from, for example, the additional thermodynamic work needed in the data center to cool the air. In one respect, racks are typically cooled with fans that operate to move cooling air across the heat dissipating components; whereas, data centers often implement reverse power cycles to cool heated return air. The additional work required to achieve the temperature reduction, in addition to the work associated with moving the cooling fluid in the data center and the condenser, often add up to the 50 percent power requirement. As such, the cooling of data centers presents problems in addition to those faced with the cooling of the racks.

Conventional data centers are typically cooled by operation of one or more computer room air conditioning (CRAC) units. For example, compressors of CRAC units typically consume a minimum of about thirty (30) percent of the required operating energy to sufficiently cool the data centers. The other components, for example, condensers and air movers (fans), typically consume an additional twenty (20) percent of the required total operating energy. As an example, a high density data center with 100 racks, each rack having a maximum power dissipation of 10 KW, generally requires 1 MW of cooling capacity. CRAC units with a capacity of 1 MW of heat removal generally requires a minimum of 300 KW input compressor power in addition to the power needed to drive the air moving devices, for instance, fans and blowers. Conventional data center CRAC units do not vary their cooling fluid output based on the distributed needs of the data center. Instead, these CRAC units generally operate at or near a maximum compressor power level even when the heat load is reduced inside the data center.

The substantially continuous operation of the CRAC units is generally designed to operate according to a worst-case scenario. For example, CRAC units are typically designed around the maximum capacity and redundancies are utilized so that the data center may remain on-line on a substantially continual basis. However, the computer systems in the data center may only utilize around 30–50% of the maximum cooling capacity. In this respect, conventional cooling systems often attempt to cool components that may not be operating at a level which may cause their temperatures to exceed a predetermined temperature range. Consequently, many conventional cooling systems often incur greater amounts of operating expenses than may be necessary to sufficiently cool the heat generating components contained in the racks of data centers.

Other types of conventional CRAC units are configured to vary the temperature of the cooling fluid as well as the volume flow rate of the cooling fluid supplied into the data center. These types of CRAC units often include cooling systems configured to vary the temperature of the received cooling fluid prior to delivery into the data center. The cooling systems include variable capacity compressors and chilled water systems. In addition, these CRAC units also include blowers with variable frequency drives configured to vary the volume flow rate of the cooling fluid delivered into the data center.

Conventionally, data centers are initially designed based upon uniform criteria for thermal management irrespective of rack configuration and power density. In this regard, data centers are typically designed without regard to the effects of heterogeneous heat loads and airflow. Instead, data centers are typically designed based upon intuition as the primary tool to guide the placement and re-arrangement of data center cooling infrastructures and resources. Consequently, conventional data centers oftentimes have infrastructures that are not efficiently designed for varying heat loads and airflows. In this regard, the energy required to cool the components contained in the racks is usually consumed in inefficient manners as additional energy is required to compensate for the non-optimized data center layouts.

SUMMARY OF THE INVENTION

In a method for evaluating one or more components in a data center, inlet and outlet temperatures of one or more heat dissipating devices are detected. In addition, the temperatures of air supplied by one or more computer room air conditioning (CRAC) units are also detected. Indices of air re-circulation for the one or more heat dissipating devices are calculated based upon the detected inlet temperatures, outlet temperatures and supplied air temperatures. The indices of air re-circulation are determined at various flow field settings of air delivered to the one or more heat dissipating devices and the one or more components are evaluated based upon changes in the indices of air re-circulation for the one or more heat dissipating devices at the various flow field settings.

BRIEF DESCRIPTION OF THE DRAWINGS

Features of the present invention will become apparent to those skilled in the art from the following description with reference to the figures, in which:

FIG. **1**A shows a simplified plan view of a data center, according to an embodiment;

FIG. **1**B shows a simplified cross-sectional side elevational view of FIG. **1**A taken along line IB—IB;

FIG. **2** illustrates a block diagram of a control system, which may be employed to perform various operations according to various embodiments;

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FIG. **3** illustrates a flow diagram of an operational mode for determining whether substantially optimized airflow conditions exist in the data center based upon SHI determinations;

FIGS. **4**A and **4**B illustrate examples of respective graphs that may be generated based upon the SHI values and the inlet temperature values for various CRAC unit volume flow rate settings;

FIG. **5** shows a flow diagram of an operational mode for at least one of evaluating the influence of CRAC units and controlling the CRAC units based upon SHI determinations at various locations of a data center;

FIG. **6** shows a flow diagram of an operational mode for evaluating airflow through a rack based upon SHI determinations at various locations of a data center; and

FIG. **7** illustrates an exemplary computer system capable of performing various operations described hereinabove with respect to FIGS. **3**, **5**, and **6**.

DETAILED DESCRIPTION OF THE INVENTION

For simplicity and illustrative purposes, the present invention is described by referring mainly to an exemplary embodiment thereof. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent however, to one of ordinary skill in the art, that the present invention may be practiced without limitation to these specific details. In other instances, well known methods and structures have not been described in detail so as not to unnecessarily obscure the present invention.

An index of air re-circulation is employed for various purposes in at least one of the layout design, deployment, and evaluation of data centers. In one respect, various air re-circulation indices are calculated for various flow field settings. The flow field settings may include, for instance, the volume flow rates of one or more CRAC units, the airflow characteristics through one or more vent tiles, the positions of adjustable panels or adjustable louvers configured to vary airflow into individual racks, the speeds of rack-mounted fans, etc. In addition, the one or more vent tiles may be positioned on a raised floor, a lowered ceiling, a delivery point of a ducted supply network, a return point of a ducted return network, etc. The calculated indices are plotted against inlet temperatures at various racks to determine how the indices vary with different flow field settings. In addition, the plotted relationships are examined to determine whether a linear relationship exists. Depending upon the linearity, or lack of linearity, airflow characteristics in a data center may be characterized. For instance, if it is determined that the airflow characteristics in the data center are substantially optimized, a determination that the data center infrastructure need not be modified may be made. Otherwise, if the airflow characteristics in the data center are not substantially optimized, a determination that the data center infrastructure requires modification may be made.

The index of air re-circulation may also be employed as a tool for evaluating CRAC unit influence to various areas of the data center. The various areas in the data center may include any reasonably suitable heat dissipating device or groups of heat dissipating devices, such as, for instance, racks, monitors, or other devices. In this example, correlations between air re-circulation indices and various flow rates of air supplied by one or more CRAC units may be employed to determine the influence of the one or more CRAC units to the various areas in the data center.

The index of air re-circulation may further be employed as a tool for evaluating air flow through various heat dissipating devices, such as, for instance, racks, monitors or other devices. In one regard, the manner in which the re-circulation of air varies at various racks in response to changing one or more flow field settings may be used to evaluate the airflow characteristics of the various racks.

Although reference is made throughout the present disclosure to racks, it should be understood that various aspects of the invention may be practiced with or on other types of heat dissipating devices. In this regard, it should be understood that the discussion of racks in the present disclosure is not meant to limit the invention, but that such discussion is made for purposes of simplicity of description.

With reference first to FIG. **1**A, there is shown a simplified plan view of a data center **100**, according to an embodiment. The terms "data center" are generally meant to denote a room or other space and are not meant to limit the invention to any specific type of room where data is communicated or processed, nor should it be construed that use of the terms "data center" limits the invention in any respect other than its definition hereinabove.

As shown in the FIG. **1**A, the data center **100** includes a plurality of rows of racks **102**–**114**, for instance, electronics cabinets, generally positioned in substantially parallel rows. Each of row of racks **102**–**114** is illustrated as containing five racks. With reference to the row of racks **102**, the racks forming the row of racks **102**–**114** are depicted as including racks **102***a*–**102***e*. The racks contained in each of the rows of racks **102**–**114** house one or more components (not shown). These components may include, for instance, computers, servers, monitors, hard drives, disk drives, etc., designed to perform various operations. Some operations of the components may include, for instance, computing, switching, routing, displaying, etc. These components may comprise subsystems (not shown), for example, processors, microcontrollers, high-speed video cards, memories, semiconductor devices, and the like to perform these functions. In the performance of these electronic functions, the components, and therefore the subsystems, generally dissipate relatively large amounts of heat. Because racks have been known to include upwards of forty (40) or more subsystems, they may dissipate substantially large amounts of heat. Cooled air, or other type of fluid for cooling the components, is therefore supplied to generally flow around and through the components to absorb the dissipated heat through convection, to maintain the subsystems and the components generally within predetermined operating temperature ranges.

The cooled air is illustrated as being supplied through vent tiles **116** in the floor **118** of the data center **100**. The vent tiles **116** are illustrated as being variously positioned to supply cooled air to the racks **102***a*–**114***e*. As will be seen in FIG. **1**B, the floor **118** is a raised floor with a space therebelow. The space generally enables power lines, communication lines, and other wires (not shown), to be located below the floor **118** such that the wires and communication lines are substantially positioned away from an upper surface of the floor **118**. The space may also function as a plenum for delivery of cooled air from variously positioned computer room air conditioner (CRAC) units **120***a*–**120***e* to the racks **102***a*–**114***e*.

As shown in FIG. **1**A, the CRAC units **120***a*–**120***e* are positioned to supply cooled air to various regions of the data center **100**. In addition, some of the cooled air delivered to certain sections of the data center **100** may include cooled air supplied by more than one CRAC unit, for

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The aisles **122** between the racks **102***a*–**114***e* having vent tiles **116** located therebetween may be considered as cool aisles. These aisles **122** are considered "cool aisles" because they are configured to receive cooled air from the vent tiles **116**. The aisles **124** between the racks **102***a*–**114***e* that do not have vent tiles **116** may be considered as hot aisles because they are positioned to receive air that has been heated by the components in the racks **102***a*–**114***e*.

Also illustrated in FIG. **1**A is a computing device **126**. The computing device **126** may comprise a computer system, a controller, microprocessor, etc., configured to control operations of one or more of the CRAC units **120***a*–**120***e*. More particularly, the computing device **126** may be configured, for instance, to receive input from sensors (not shown) and to vary operations of the various variable controllable systems contained in one or more of the CRAC units **120***a*–**120***e*. The computing device **126** may also be configured to receive input from a user, for instance, data center personnel, an administrator, a manager, etc. The input received from a user may comprise various set points by which the computing device **126** may determine how and when to manipulate the operations of the variable controllable systems.

The computing device **126** may communicate with one or more of the CRAC units **120***a*–**120***e* via wired communication lines (not shown). However, it should be understood that communications between one or more of the CRAC units **120***a*–**120***e* and the computing device **126** may be effectuated through a wireless protocol, such as IEEE 802.11b, 802.11g, wireless serial connection, Bluetooth, etc., or combinations thereof, without departing from a scope of the invention. In addition, although a single computing device **126** is illustrated, each of the CRAC units **120***a*–**120***e* may include their own respective computing device **126**. Moreover, the computing device **126** may comprise controllers that are integrally formed or otherwise form part of each of the CRAC units **120***a*–**120***e*. Thus, although the data center **100** has been illustrated as containing a certain configuration, it should readily be understood that various other configurations are possible for the data center **100** without departing from a scope of the invention.

The data center **100** depicted in FIG. **1**A represents a generalized illustration and other components may be added or existing components may be removed or modified without departing from the scope of the invention. For example, the data center **100** may include any number of racks and various other apparatuses known to be housed in data centers. Thus, although the data center **100** is illustrated as containing seven rows of racks **102**–**114**, it should be understood that the data center **100** may include any number of racks, for instance, 100 or more racks, without departing from the scope of the invention. In addition, each of the rows of racks **102**–**114** may contain any number of racks. The depiction of the racks **102***a*–**114***e* is thus for illustrative and simplicity of description purposes only and is not intended to limit the invention in any respect. As another example, the data center **100** may include any number of CRAC units **120***a*–**120***e*, each having a number of different types of cooling systems.

The data center **100** may also include a lowered ceiling (not shown) configured with returns for receiving heated cooling fluid from within the data center **100**. The lowered ceiling may also include or form a plenum for directing the heated cooling fluid to the CRAC units **120***a*–**120***e*. An example of a data center **100** having a lowered ceiling may be found in co-pending and commonly assigned U.S. patent application Ser. No. 10/262,879, filed on Apr. 17, 2002, the disclosure of which is hereby incorporated by reference in its entirety.

With reference now to FIG. **1**B, there is shown a simplified cross-sectional side elevational view of FIG. **1**A taken along line IB—IB. FIG. **1**B represents a generalized illustration and other components may be added or existing components may be removed or modified without departing from the scope of the invention as described hereinabove. More particularly, FIG. **1**B shows the CRAC unit **120***d* and the racks, **102***b*, **104***b*, **106***b*, **108***b*, **110***b*.

In general, air or other cooling fluid is received by the CRAC units **120***a*–**120***e* and is cooled through heat transfer with coolant in the CRAC units **120***a*–**120***e*. In the example illustrated in FIG. **1**B, the CRAC unit **120***d* is configured as a chiller-type air conditioning unit. In this regard, the CRAC unit **120***d* includes a three-way valve **130** configured to control the flow of coolant through a cooling coil **132**. The three-way valve **130** as well as other components of the CRAC unit **120***d* may be operated in manners consistent with conventional chiller-type air conditioning units. Alternatively, the CRAC unit **120***d* may be configured as a conventional chiller-type air conditioning unit having a two-way valve. As a further alternative, the CRAC unit **120***d* may be configured as a vapor-compression type air conditioning unit in which a conventional vapor-compression cycle may be employed to cool air received into the CRAC unit **120***d*. In addition, the other CRAC units **120***a*–**120***c* and **120***e* may also be configured as chiller-type or vapor compression type of air conditioning units.

The CRAC unit **120***d* also includes a blower **134** that may be controlled to vary the volume flow rate of air delivered into a space **138** located beneath the raised floor **118**. The speed or the output of the blower **134** may be controlled through use of any reasonably suitable and commercially available variable frequency drive (VFD) **136**, which is shown as being positioned adjacent to the blower **134**. The VFD **136** generally operates to control the blower **134** to vary the volume flow rate of airflow into and out of the CRAC unit **120***d*.

The arrow **140** generally indicates the heated airflow path into the CRAC unit **120***d*. In general, through heat exchange with the coolant contained in the cooling coil **132**, heat is removed from the air received into the CRAC unit **120***d*. In addition, the cooled air is supplied into the data center **100** through operation of the blower **134**, as indicated by the arrow **142**. The computing device **126** may be configured to control the temperature of the coolant contained in the cooling coil **132** and speed of the blower **134** to thereby control the cooling of the air and the volume flow rate of the supplied air.

In certain instances, each of the CRAC units **120***a*–**120***e* may be operated in substantially independent manners. For example, one or both of the temperature and the volume flow rate of air delivered by each of the CRAC units **120***a*–**120***e* may differ for one or all of the CRAC units **120***a*–**120***e*. In one regard, one or both of the temperature and the volume flow rate of air delivered to various sections of the data center **100** may differ from one or both of the temperature and the volume flow rate of air supplied by any individual CRAC unit **120***a*–**120***e*.

The temperatures of the cooled air supplied by the CRAC units **120***a*–**120***e* may be detected by temperature sensors, for instance, the temperature sensor **144** depicted in FIG. **1**B. As shown, the temperature sensor **144**, hereinafter, supply temperature sensor **144**, is positioned to detect the temperature of the airflow supplied by [illegible]

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Although the supply temperature sensor **144** is illustrated as being attached to a bottom surface of the raised floor **118** proximate the outlet of the CRAC unit **120***d*, the supply temperature sensor **144** may be positioned at any reasonably suitable location where the supply temperature sensor **144** may detect the temperature of the air supplied by the CRAC unit **120***d*. This is also true for the other CRAC units **120***a*–**120***d* and **120***e*.

Additional temperature sensors **146** and **148**, hereinafter inlet temperature sensors **146** and outlet temperature sensors **148**, are also illustrated in FIG. **1**B. As the name implies, the inlet temperature sensors **146** are configured to detect the temperatures of cooled air supplied through the vent tiles **116**. In addition, the outlet temperature sensors **148** are configured to detect the temperatures of the heated air exhausted from the racks **102***a*–**114***e*. Although not explicitly shown, some or all of the racks **102***a*–**114***e* may contain the inlet temperature sensors **146** and the outlet temperature sensors **148**. Through use of the inlet temperature sensors **146** and the outlet temperature sensors **148**, the changes in temperatures of the airflow through individual racks **102***a*–**114***e* equipped with the sensors **146**, **148** may be determined. The placements of the inlet temperature sensors **146** and the outlet temperature sensors **148** with respect to their associated racks **102***a*–**102***e* are for illustrative purposes only and are not meant to limit the data center **100** in any respect. Instead, the inlet temperature sensors **146** and the outlet temperature sensors **148** may be positioned at any reasonably suitable locations without departing from a scope of the data center **100**.

Although reference is made in FIG. **1**B to the use of the blower **134** to draw heated air from the data center **100**, it should be understood that any other reasonably suitable manner of heated air removal from the data center **100** may be implemented without departing from the scope of the invention. By way of example, a separate fan or blower (not shown) may be employed to draw the heated air from the data center **100**. In addition, the CRAC units **120***a*–**120***d* may include at least one of a humidifier and a dehumidifier as is known to those of ordinary skill in the art.

FIG. **2** illustrates a block diagram **200** of a control system **202** which may be employed to perform various operations according to various embodiments. The following description of the block diagram **200** is one manner of a variety of different manners in which such a control system **202**, may be configured. In addition, it should be understood that the block diagram **200** may include additional components and that some of the components described herein may be removed or modified without departing from the scope of the invention.

The control system **202** includes a controller **204** for controlling various operations of the control system **202**. The controller **204** may, for instance, comprise the computing device **126** and thus may also comprise a microprocessor, a micro-controller, an application specific integrated circuit (ASIC), and the like. The controller **204** may, alternatively, comprise a separate computing device.

As shown, the controller **204** is configured to receive temperature data from two racks, rack A **206** and rack B **208**, which may be configured as any of the racks **102***a*–**114***e* depicted in FIGS. **1**A and **1**B. Each of the racks **206** and **208** is configured with respective inlet temperature sensors **210** and **212** and respective outlet temperature sensors **214** and **216**. The temperature measurements obtained by the sensors **210**–**216** are sent to the controller **204**. Information from the sensors **210**–**216** may be sent to the controller **204** through, for instance, an Ethernet-type connection or through a wired protocol, such as IEEE 802.3, etc., or wireless protocols, such as IEEE 802.11b, 802.11g, wireless serial connection, Bluetooth, etc., or combinations thereof. Although two racks **206** and **208** are depicted in FIG. **2**, the controller **204** may be configured to receive temperature data from temperature sensors **146**, **148** positioned around any number of racks, including all of the racks **102***a*–**114***e* shown in FIGS. **1**A and **1**B.

The controller **204** may store these measurements in a memory **218**. The memory **218** may also store programs or other software, which the controller **204** may access in performing various operations as described in greater detail hereinbelow. In any regard, the memory **218** may comprise a traditional memory device, such as, volatile or non-volatile memory, such as DRAM, EEPROM, flash memory, combinations thereof, and the like.

As also shown in FIG. **2**, the controller **204** is configured to receive various data from two CRAC units, CRAC unit A **220** and CRAC unit B **222**, which may be configured as any of the CRAC units **120***a*–**120***e* shown in FIG. **1**A. Although two CRAC units **220** and **222** are depicted in FIG. **2**, the controller **204** may be configured to receive data from any number of CRAC units, including all of the CRAC units **120***a*–**120***e* shown in FIG. **1**A. In any regard, the CRAC units **220** and **222** are configured with respective supply temperature sensors **224** and **226**. The temperature measurements obtained by the supply temperature sensors **224** and **226** are sent to the controller **204**. The CRAC units **220** and **222** are also configured with respective VFDs **228** and **230**.

The controller **204** may be configured to operate the VFDs **228** and **230** to vary the volume flow rate of air supplied by each of the CRAC units **228** and **230**. In addition, the volume flow rates may be calculated by the controller **204** through a determination of the VFD **228** and **230** speeds. Alternatively, the volume flow rates may be detected through use of separate sensors, for instance, anemometers positioned to detect the velocities of the supply air. Information from the supply temperature sensors **224** and **226** and the VFDs **228** and **230** may be sent to the controller **204** through, for instance, an Ethernet-type connection or through a wired protocol, such as IEEE 802.3, etc., or wireless protocols, such as IEEE 802.11b, 802.11g, wireless serial connection, Bluetooth, etc., or combinations thereof. In addition, the controller **204** may be configured to store the information received from the supply temperature sensors **224** and **226** and the VFDs **228** and **230** in the memory **218**.

The memory **218** may also store an algorithm, for instance, in the form of software, configured to calculate an air re-circulation index based upon some of the information received from the inlet temperature sensors **210** and **212**, the outlet temperature sensors **214** and **216** and the supply temperature sensors **224** and **226**. The index of air re-circulation may be defined as a supply heat index (SHI). The SHI may be defined as a measure of the infiltration of heated air into the cooled air. The SHI of a particular rack (i) may be determined according to the following equation:

$$(SHI)_i = \frac{\delta Q}{Q + \delta Q} \qquad \text{Equation (1)}$$

Where Q represents the heat dissipation from all the components in the rack (i) and δQ represents the rise in enthalpy of the cooled air before entering the rack (i).

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The heat dissipation Q and the rise in enthalpy of the air δQ of the rack (i) may be determined through the following equations:

$$Q_i = mC_p(T_{out} - T_{in}) \quad \text{Equation (2)}$$

$$\delta Q_i = mC_p(T_{in} - T_{ref}) \quad \text{Equation (3)}$$

Where m is the mass flow rate through the rack (i), C_p is the specific heat capacity of the air supplied to the rack (i), and (T_{in}) and (T_{out}) are the inlet and outlet temperatures of the rack (i). In addition, T_{ref} denotes the vent tile **116** air supply temperature, which may be equivalent to the supply air temperature of the CRAC unit **120***a*–**120***e* in closest proximity to the rack (i). Incidentally, and as discussed hereinabove, the supply air temperatures may differ due to differences in the supply air temperatures of the CRAC units **120***a*–**120***e*.

The numerator in equation 1 denotes the sensible heat gained by the air supplied by the CRAC units **120***a*–**120***e* before entering the rack (i), while the denominator represents the sensible heat gained by the air leaving the rack (i). Because the mass flow rates are equal for equations 2 and 3, SHI may be written as a function of rack inlet, rack outlet and CRAC unit **120***a*–**120***e* supply temperatures. Thus, SHI may be represented as follows:

$$SHI_i = \left(\frac{T_{in} - T_{ref}}{T_{out} - T_{ref}}\right) \quad \text{Equation 4}$$

A more detailed description of SHI may be found in co-pending and commonly assigned U.S. patent application Ser. No. 10/446,854, filed on May 29, 2003. The disclosure contained in that Application is incorporated herein by reference in its entirety.

Thus, for instance, the controller **204** may determine the SHIs for the racks **206** and **208** through implementation of the algorithm described hereinabove. As an example, the controller **204** may determine the SHI for rack A **206** based upon the inlet temperature measured by the inlet temperature sensor **210**, the outlet temperature measured by the outlet temperature sensor **214**, and the reference or supply temperatures of one or both of the CRAC units **220** and **222**. The reference or supply temperature used in the SHI calculations for the racks **206** and **208** may be determined in a variety of manners. For instance, if it is known that a particular rack **206** or **208** receives cooled air from a single CRAC unit **220** or **222**, the temperature of the cooled air supplied by that CRAC unit **220** or **222** may be used as the reference temperature in determining SHI. Thus, the reference or supply temperature used in the SHI calculations may be based upon historical data. Alternatively, a sensor may be positioned to detect the temperature of the cooled air supplied through a vent tile **116** arranged supply a particular rack **206** or **208** with the cooled air. In this example, the temperature detected by that sensor may be used as the reference or supply temperature.

As another example, a metric may be developed that describes the effect of any CRAC unit **220**, **222** on a rack **206**, **208**. In this example, the metric may be developed through perturbation of CRAC **220**, **222** air supply temperature by predefined amounts along with detection of temperatures at the inlets of the racks **206**, **208**. Based upon the supply air temperature and the detected inlet temperature, a sensitivity correlation may be developed with cooled air temperature and flow rate as variables. In addition, metrics from various CRAC units **220**, **222** may be combined to determined combined effects on inlet temperatures to various racks **206**, **208**. The sensitivity correlation may be used to determine the effects of various CRAC units **220**, **222** on particular racks **206**, **208** and the reference or supply temperature used in the SHI calculation may be determined through implementation of the sensitivity correlation.

The memory **218** may also store additional algorithms or software configured to perform various operations as will be described in greater detail with reference to the following operational modes.

FIG. **3** illustrates a flow diagram of an operational mode **300** for determining whether substantially optimizied airflow conditions exist in the data center **100** based upon SHI determinations. It is to be understood that the following description of the operational mode **300** is one manner of a variety of different manners in which the airflow in the data center **100** may substantially be optimized. It should also be apparent to those of ordinary skill in the art that the operational mode **300** represents a generalized illustration and that other steps may be added or existing steps may be removed, modified or rearranged without departing from a scope of the invention.

The description of the operational mode **300** is made with reference to the block diagram **200** illustrated in FIG. **2**, and thus makes reference to the elements cited therein. It should, however, be understood that the operational mode **300** is not limited to the elements set forth in the block diagram **200**. Instead, it should be understood that the operational mode **300** may be practiced by control systems having different configurations than the configuration set forth in the block diagram **200**.

The operational mode **300** may be initiated or started at step **302**, for instance, by activating one or more CRAC units **220**, **222**, activating one or more components in the data center **100**, etc. In addition, or alternatively, the operational mode **300** may be manually initiated, after a predetermined period of time, etc.

At step **304**, the temperatures of the airflow delivered into one or more racks **206**, **208** may be detected with respective inlet temperature sensors **210**, **212**. In addition, the temperatures of the airflow exhausted from one or more racks **206**, **208** may be detected with respective outlet temperature sensors **214**, **216**. These temperature measurements may be sent to the controller **204** as described hereinabove. In addition, the controller **204** may store the received information along with the associated rack **206**, **208** from which the information was received. In this regard, the inlet temperatures and the outlet temperatures of each rack **206**, **208** may be stored along with their associated rack **206**, **208**. This information may be stored, for instance, in the form of a look-up table that associates the racks **206**, **208** along with their inlet and outlet temperatures.

The controller **204** may also receive the temperatures of air supplied by one or more CRAC units **220**, **222** detected by respective supply temperature sensors **224**, **226**, at step **306**. The controller **204** may store this information in the memory **218** along with the identifications of the one or more CRAC units **220**, **222** associated with the temperature sensors **224**, **226**. Again, this information may be stored, for instance, in the form of a look-up table that associates the CRAC units **220**, **222** with the temperature measurements.

At step **308**, the controller **204** may calculate the SHIs of the one or more racks **206**, **208** in a manner as described hereinabove with respect to FIG. **2**. More particularly, for a particular rack, the controller **204** may calculate the difference in inlet temperature and reference [illegible]

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temperature) divided by the difference in outlet temperature and the reference temperature (supply temperature). The controller **204** may also store the calculated SHIs for the various racks **206**, **208** in the memory **218** in addition to the inlet temperatures of the various racks **206**, **208**, as indicated at step **310**.

At step **312**, the controller **204** may compare the SHI(s) of the various racks **206**, **208** with their associated inlet temperatures. The controller **204** may further store this comparison in the memory **218**. At step **314**, the controller **204** may also receive information pertaining to the volume flow rate of air supplied by one or more CRAC units **220**, **222**. The controller **204** may determine the volume flow rate through a correlation between the VFD **228**, **230** speed and the known volume flow rate of air at the detected VFD **228**, **230** speed. The correlation between the VFD **228**, **230** speed and the volume flow rate may be supplied by the VFD **228**, **230** manufacturer or it may determined through testing of the VFD **228**, **230**. Alternatively, a separate sensor (not shown), for instance, an anemometer, may be employed to detect the velocity of airflow and a volume flow rate may be calculated through any reasonably suitable known means. In any regard, the controller **204** may store the volume flow rate information of the one or more CRAC units **220**, **222** in the memory **218**.

The controller **204** may create a plot of the SHI(s) vs. the inlet temperature(s) of the various racks **206**, **208** for a given flow field setting, at step **316**. In addition, at step **318**, the controller **204** may determine whether additional plots should be obtained. If additional plots are to be obtained, the controller **204** may control or otherwise cause one or more flow field settings to be changed at step **320**. The flow field settings may include the volume flow rates of one or more CRAC units **220**, **222**, the airflow characteristics through one or more vent tiles **116**, the positions of adjustable panels or adjustable louvers configured to vary airflow into individual racks, the speeds of rack-mounted fans, etc. In addition, the one or more vent tiles may be positioned on a raised floor, a lowered ceiling, a delivery point of a ducted supply network, a return point of a ducted return network, etc. The adjustable panels were described in co-pending and commonly assigned U.S. patent application Ser. No. 10/425,624, and the adjustable louvers were described in co-pending and commonly assigned U.S. patent application Ser. No. 10/425,621, both of which were filed on Apr. 30, 2003. In addition, the disclosures of these applications are incorporated herein by reference in their entireties.

The changes to airflow characteristics through one or more vent tiles **116** may be performed either manually or through use of computer controlled vent tiles. An example of computer controlled vent tiles may be found in commonly assigned U.S. Pat. No. 6,574,104, the disclosure of which is incorporated herein by reference in its entirety. In addition, steps **304**–**320** may be repeated for the various flow field settings. In this regard, the SHI values and the inlet temperature values may be plotted for various CRAC unit **220**, **222** supply volume flow rates. FIGS. **4**A and **4**B illustrate examples of respective graphs **400** and **450** that may be generated by the controller **204** based upon the SHI values and the inlet temperature values for various flow field settings.

When the re-circulation heat load caused by hot air infiltration is negligible compared to the actual heat loads, equation (1) may be reduced to a linear equation in SHI, as follows:

$$SHI_i = \left(\frac{T_{in} - T_{ref}}{(T_{out} - T_{in}) + (T_{in} - T_{ref})}\right) = \frac{\delta Q}{Q} = \frac{T_{in} - T_{ref}}{X_i} \quad \text{Equation (5)}$$

Where $X_i=(T_{out}-T_{in})$ denotes the temperature difference due to actual heat load of the i^{th} rack. FIG. **4**A shows the variation of SHI based upon equation (1) with rack inlet temperatures for racks in a row for different flow field settings. The linear dependence of the plots in FIG. **4**A follows the relationship shown in equation (2), thereby indicating that the re-circulation heat load is negligible relative to the actual heat loads in the racks.

For the plots in graphs **400** and **450**, the racks were held under constant heat loads for the various CRAC unit **220**, **222** flow settings. In addition, a reference straight line **402** is illustrated to show, for instance, that the SHI vs. inlet temperature plots for the rack(s) having 10 kW heat loads is nearly linear in the graph **400**. More particularly, at the various CRAC unit **220**, **222** flow settings as indicated by the different symbols, the SHI values vs. the inlet temperatures are nearly linear for the racks.

The graphs **400** and **450** show respective relationships between SHI values and rack inlet temperatures for a plurality of racks at various flow field settings. Each of the different symbols represents a different flow field setting. In addition, each of the symbols may represent one or more racks at the different flow field settings. Thus, for instance, one circle in the graph **400** may represent a first rack or racks and another circle may represent a second rack or racks at a first flow field setting. In addition, a square may represent the first rack(s) at and another square may represent the second rack(s) at a second flow field setting.

In comparing the graphs **400** and **450**, it is clearly evident that the plots in graph **400** are nearly linear whereas the plots in graph **450** are not arranged in a linear relationship. Thus, the graph **450** generally denotes that the re-circulation heat load caused by hot air infiltration is significant compared to the actual heat loads. Therefore, the graph **450** generally indicates that there may be adverse airflow patterns in the data center **100** which may lead to, for instance, inefficient CRAC unit **220**, **222** operations as well as inefficient heat removal from the racks.

Referring back to FIG. **3**, particularly to step **318**, if no additional plots are to be obtained, for instance, a predetermined number of SHI and inlet temperature values have been obtained, the graph, for instance, as illustrated in the graphs **400** and **450**, may be analyzed to determine whether the relationships between the SHI values and the inlet temperatures are nearly linear at step **322**. As shown in FIG. **4**A, the plots of the SHI values and the inlet temperatures for various racks at various supply volume airflow rates are nearly linear for racks having different heat loads. Thus, linearity may be determined through a visual inspection of the graph.

Alternatively, the degree of linearity among the plots may be computed according to the square of the correlation coefficient (R). The correlation coefficient (R) defines the degree of linear relationship between variables measured from an original data and can range from 0, which is completely non-linear to 1, which is completely linear. Based upon the plots in the graph, either graph **400** or **450**, a correlation coefficient may be calculated. In addition, an error factor may be considered in determining whether the plots are nearly linear. Thus, for instance, [illegible]

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of the correlation coefficient (R) does not equal 1, if it is nearly equal to one. for instance, if $R^2>0.9$. the plots may be considered as being nearly linear. The determination of the acceptable level of deviation from $R^2=1$ while still considering the plots to be nearly linear may be based upon a number of factors.

By way of example, a relatively arbitrary correlation coefficient, for instance, 0.9, may be selected as a lower boundary for considering the plots as being nearly linear. As another example, the lower boundary for the correlation coefficient may be determined through testing configured to indicate correlations between acceptable SHI levels and correlation coefficients. As a further example, the lower boundary for the correlation coefficient may be based upon known uncertainties in the determination of the SHI values inputted into the graph. In this example, for instance, the degree of uncertainty in measuring one or more of the inlet temperatures, the outlet temperatures, and the supply air temperatures may be used to determine the lower boundary for the correlation coefficient.

Regardless of the manner in which the lower boundary for the correlation coefficient is defined, the correlation coefficients for plots obtained for various locations in the data center **100** need not be the same for the various locations.

If, at step **322**, it is determined that the relationship between the SHI(s) vs. the inlet temperatures of the racks is nearly linear, for instance, as shown in FIG. **4**A, the controller **204** may be configured to output an indication that the data center **100** infrastructure need not be changed as step **324**. The data center **100** infrastructure may include the positioning of the CRAC units **220**, **222**, the vent tiles **116**, the racks **206**, **208**, etc. In any regard, as described hereinabove with respect to FIG. **4**A, nearly linear SHI vs. inlet temperature values is an indication that the re-circulation heat load caused by hot air infiltration is negligible compared to the actual heat loads. In other words, the data center **100** layout may be considered as being nearly optimized in terms of airflow optimization.

Alternatively, if at step **322**, it is determined that the relationship between the SHI(s) vs. the inlet temperatures of the racks is not nearly linear, for instance, as shown in FIG. **4**B, the controller **204** may output an indication that the data center **100** infrastructure requires changes at step **326**. As described hereinabove with respect to FIG. **4**B, this situation is indicative of re-circulation heat load due to hot air infiltration being significant compared with the actual heat loads in the racks. In one regard, the infrastructure changes may be made to substantially reduce SHI values as well as to obtain plots having nearly linear SHI vs. inlet temperature values to thus substantially optimize airflow in the data center **100**.

Through implementation of the operational mode **300**, airflow characteristics in the data center **100** may be determined and substantially optimized to reduce or minimize, for instance, hot air re-circulation into the racks.

A computational fluid dynamics (CFD) tool programmed to model airflow patterns for various data center configurations may be employed to perform the operational mode **300**. More particularly, the CFD tool may be programmed to calculate the SHI values for various areas in the variously configured data centers based upon different CRAC flow settings and to plot the calculated SHI values as shown in FIGS. **4**A and **4**B. By way of example, some or all of the inputs, for instance, heat loads in the racks, volume flow rates of air supplied by one or more CRAC units, the layout of the data center, etc., may be manually inputted into the CFD tool. In this regard, the CFD tool may be configured to determine various variables, such as, rack inlet and outlet temperatures, volume flow rates, SHI values, etc., based upon calculated airflow characteristics in the data center **100** and the inputted information.

In addition, the CFD tool may be programmed to determine whether the plots denote a nearly linear relationship. In one regard, if the plots do not denote a nearly linear relationship, the CFD tool may be programmed to substantially continuously re-configure the data center infrastructure until a nearly linear relationship is established. Consequently, a CFD tool employing the operational mode **300** may be used as a tool for designing the layout of the data center, such that, for instance, airflow in the data center may be substantially optimized.

With reference now to FIG. **5**, there is shown a flow diagram of an operational mode **500** for at least one of evaluating the influence of CRAC units **220**, **222** and controlling the CRAC units **220**, **222** based upon SHI determinations at various locations of a data center **100**. It is to be understood that the following description of the operational mode **500** is one manner of a variety of different manners in which the airflow in the data center **100** may substantially be optimized. It should also be apparent to those of ordinary skill in the art that the operational mode **500** represents a generalized illustration and that other steps may be added or existing steps may be removed, modified or rearranged without departing from a scope of the invention.

The description of the operational mode **500** is made with reference to the block diagram **200** illustrated in FIG. **2**, and thus makes reference to the elements cited therein. It should, however, be understood that the operational mode **500** is not limited to the elements set forth in the block diagram **200**. Instead, it should be understood that the operational mode **500** may be practiced by control systems having different configurations than the configuration set forth in the block diagram **200**.

The operational mode **500** may be initiated or started at step **502**, for instance, by activating one or more CRAC units **220**, **222**, activating one or more components in the data center **100**, etc. In addition, or alternatively, the operational mode **500** may be manually initiated, after a predetermined period of time, etc.

Steps **304**–**308** are the same as those steps described hereinabove with respect to FIG. **3**. Therefore, a detailed description of these steps is not reproduced. Instead, the description of steps **304**–**308** set forth hereinabove is relied upon as providing sufficient disclosure of these steps.

At step **504**, the SHI value(s) of one or more racks **206**, **208** calculated at step **308** are stored in the memory **218**. At step **506**, it is determined whether the volume flow rates of one or more CRAC units **220**, **222** is to be varied. The volume flow rate of air supplied by at least one CRAC unit **220**, **222** is varied during a first iteration of the operational mode **500**. However, the volume flow rates of one or more CRAC units **220**, **222** may not necessarily be changed during further iterations of the operational mode **500**. For instance, a "no" condition at step **506** may be reached after a predetermined number of iterations, or more particularly, when a predetermined number of SHI calculations have been obtained. The predetermined number of iterations may be based upon, for instance, the level of accuracy desired in determining whether certain racks **206**, **208** are influenced by certain CRAC units **220**, **222**. Thus, for instance, a greater number of iterations may be performed to obtain greater accuracy.

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It may be beneficial to vary the volume flow rates of air supplied by one or more CRAC units **220**, **222** without varying the temperatures of the air. In one regard, CRAC units **220**, **222** are typically configured to dehumidify or humidify the air based in conjunction with varying airflow temperatures. Therefore, by limiting the changes to volume flow rates of air supplied by the one or more CRAC units **220**, **222**, dehumidifying and humidifying operations may substantially be avoided.

If it is the first iteration of the operational mode **500** or if it is determined that the volume flow rate of at least one CRAC unit **220**, **222** is to be varied, the volume flow rates of one or more CRAC units **220**, **222** may be varied at step **508**. The determination of the volume flow rate of which CRAC unit **220**, **222** to vary may be based upon whether it is desired to know which of the CRAC units **220**, **222** has influence over a particular area or particular racks **206**, **208**. Thus, for instance, if it is desired to determine whether the CRAC unit **220** has influence over the rack **206**, the volume flow rate of air supplied by that CRAC unit **220** may be varied and the SHI of that rack **206** may be determined and stored as indicated at steps **304**–**308** and **504**. Steps **506** and **508** may be performed any number of times as indicated hereinabove. In addition, the flow rates of at least one of the CRAC units **220**, **222** may be changed to perturb existing airflow patterns in relatively small amounts. In other words, the perturbation caused by the changes in the flow rates of at least one of the CRAC units **220**, **222** may be performed, not to create a different flow pattern but to alter the extent and magnitude of existing flow patterns.

If, at step **506**, it is determined that the volume flow rates of air supplied by one or more CRAC units **220**, **222** is not to be varied, the controller **204** may compare the stored SHI values of the areas or one or more racks **206**, **208** at the various CRAC unit **220**, **222** flow settings, as indicated at step **510**. The determination to not vary the volume flow rates of the one or more CRAC units **220**, **222** may be reached when, for instance, sufficient SHI values have been calculated to achieve a predetermined level of accuracy in determining the influence of the CRAC units **220**, **222** on the various areas or racks **206**, **208**.

At step **512**, the controller **204** may determine whether the SHI levels for one or more areas have changed for at least two different CRAC unit **220**, **222** flow settings. If no change is detected at step **512**, the controller **204** may output an indication that the one or more areas are not influenced by the one or more CRAC units **220**, **222** whose flow settings were changed, at step **514**. Thus, for instance, if the SHI levels in a particular area have not changed in response to a change in the volume flow rate of at least one CRAC unit **220**, **222**, it may be assumed that one or more of the CRAC units **220**, **222** do not influence the one or more areas. In addition, it may be assumed that changes in the outputs of these one or more CRAC units **220**, **222** will not affect the cooling of these one or more areas. Therefore, as these one or more areas undergo varying heat load conditions, these one or more CRAC units **220**, **222** do not necessarily have to be manipulated to compensate for these changing heat load conditions.

If, at step **512**, the controller **204** determines that the SHI levels for the one or more areas have changed, the controller **204** may output an indication that the one or more areas are influenced by the one or more CRAC units **220**, **222** whose flow settings were changed, at step **516**. Thus, for instance, if the SHI levels in a particular area have changed in response to a change in the volume flow rate of at least one CRAC unit **220**, **222**, it may be assumed that one or more of the CRAC units **220**, **222** have influence over the one or more areas. In addition, it may be assumed that changes in the outputs of these one or more CRAC units **220**, **222** will affect the cooling of these one or more areas. Therefore, as these one or more areas undergo varying heat load conditions, these one or more CRAC units **220**, **222** may be manipulated to compensate for these changing heat load conditions.

In addition to step **516**, the controller **204** may determine the level of influence over the one or more areas by the one or more CRAC units **220**, **222** at step **518**. Moreover, the controller **204** may output an indication of the level of influence over one or more areas by one or more CRAC units **220**, **222** at step **520**. Thus, for instance, the controller **204** may determine the levels of SHI level changes and correlate that to the level of influence of the one or more CRAC units **220**, **222**. By way of example, the controller **204** may determine that one or more of the CRAC units **220**, **222** have greater levels of influence if the changes in SHI levels are greater in response to changes in the volume flow rates of air supplied by those one or more CRAC units **220**, **222**. In contrast, if the changes in SHI levels are smaller in response to changes in the volume flow rates of air supplied by those one or more CRAC units **220**, **222**, the level of influence by those one or more CRAC units **220**, **222** may be considered as being smaller. Through knowledge of the varying levels of influence over one or more areas by the one or more CRAC units **220**, **222**, individual operations of the CRAC units **220**, **222** may substantially be tailored to, for instance, maximize efficiency and energy utilization in response to changing conditions in the data center **100**.

In another regard, the operational mode **500** may be implemented to detect problems in the cooling infrastructure of the data center **100**. By way of example, if it is known that one or more CRAC units **220**, **222** should influence a particular area of the data center **100**, but that variations in the volume flow rates of air supplied by the one or more CRAC units **220**, **222** do not result in variations in SHI levels in that particular area, it may be assumed that a problem exists with either the CRAC units **220**, **222** or the configuration of the vent tiles **116**. Based upon this information, the CRAC units **220**, **222** or the vent tiles **116** may be more closely examined to determine whether they are malfunctioning.

As with the operational mode **300** in FIG. **3**, a computational fluid dynamics (CFD) tool programmed to model airflow patterns for various data center configurations may be employed to perform the operational mode **500**. By way of example, some or all of the inputs, for instance, heat loads in the racks, volume flow rates of air supplied by one or more CRAC units, the layout of the data center, etc., may be manually inputted into the CFD tool. More particularly, the CFD tool may be programmed to calculate the SHI values for various areas in the variously configured data centers based upon different CRAC flow settings and to calculate SHI values based upon the different CRAC flow settings.

The CFD tool may also be programmed to determine if the SHI levels for particular areas vary in response to the different CRAC flow settings and to therefore determine whether one or more of the CRAC units influence the particular areas of the data center. In addition, the CFD tool may be further programmed to determine the level of influence one or more CRAC units have over the particular areas based upon the levels of SHI level changes described hereinabove. Consequently, a CFD tool employing the operational mode **500** may be used as a tool for evaluating the influence of one or more CRAC [illegible]

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in a data center. The influences of the one or more CRAC units may be used, for instance, to substantially optimize provisioning of cooling to the various areas of the data center. In one respect, the influences of the one or more CRAC units may be used as a means for selecting appropriately configured CRAC units capable of supplying sufficient cooling resources to the areas they are positioned to influence.

Turning now to FIG. **6**, there is shown a flow diagram of an operational mode **600** for evaluating airflow through a rack based upon SHI determinations at various locations of a data center **100**. It is to be understood that the following description of the operational mode **600** is one manner of a variety of different manners in which the airflow in the data center **100** may substantially be optimized. It should also be apparent to those of ordinary skill in the art that the operational mode **600** represents a generalized illustration and that other steps may be added or existing steps may be removed, modified or rearranged without departing from a scope of the invention.

The description of the operational mode **600** is made with reference to the block diagram **200** illustrated in FIG. **2**, and thus makes reference to the elements cited therein. It should, however, be understood that the operational mode **500** is not limited to the elements set forth in the block diagram **200**. Instead, it should be understood that the operational mode **500** may be practiced by control systems having different configurations than the configuration set forth in the block diagram **200**.

The operational mode **600** may be initiated or started at step **602**, for instance, by activating one or more CRAC units **220**, **222**, activating one or more components in the data center **100**, etc. In addition, or alternatively, the operational mode **600** may be manually initiated, after a predetermined period of time, etc.

Steps **304**–**308** are the same as those steps described hereinabove with respect to FIG. **3**. In addition, step **504** is the same as step **504** described hereinabove with respect to FIG. **5**. Therefore, a detailed description of these steps is not reproduced. Instead, the description of steps **304**–**308** and step **504** set forth hereinabove is relied upon as providing sufficient disclosure of these steps.

At step **604**, it is determined whether flow field settings affecting one or more areas of the data center **100** is to be varied. The flow field settings may include one or more of the volume flow rates of one or more CRAC units **220**, **222**, the layouts of one or more vent tiles **116**, the positions of adjustable panels or adjustable louvers configured to vary airflow into individual racks, the speeds of rack-mounted fans, etc. In addition, the one or more vent tiles may be positioned on a raised floor, a lowered ceiling, a delivery point of a ducted supply network, a return point of a ducted return network, etc. The flow field setting may be varied during a first iteration of the operational mode **600**. However, one or more of the flow field settings may not necessarily be changed during further iterations of the operational mode **600**. For instance, a "no" condition at step **604** may be reached after a predetermined number of iterations, or more particularly, when a predetermined number of SHI calculations have been obtained. The predetermined number of iterations may be based upon, for instance, the level of accuracy desired in determining airflow characteristics through one or more racks **206**, **208**. Thus, for instance, a greater number of iterations may be performed to obtain greater accuracy.

If it is the first iteration of the operational mode **600** or if it is determined that one or more of the flow field settings are to be varied, one or more of the flow field settings may be changed at step **606**. The determination of which of the flow field settings to manipulate may be based upon, for instance, historically known effects of the changes, an iterative process in which various changes in one or more of the flow field settings are performed to determine various outcomes, etc. In addition, the one or more of the flow field settings may be changed to perturb existing airflow patterns in relatively small amounts. In other words, the perturbation caused by the changes in one or more of the flow field settings may be performed, not to create a different flow pattern but to alter the extent and magnitude of existing flow patterns.

If, at step **604**, it is determined that one or more of the flow field settings are not to be varied, the controller **204** may compare the stored SHI values of the areas or one or more racks **206**, **208** at the various flow field settings, as indicated at step **608**. The determination to not vary one or more of the flow field settings may be reached when, for instance, sufficient SHI values have been calculated to achieve a predetermined level of accuracy in determining the airflow characteristics through one or more of the racks **206**, **208**.

At step **610**, the respective SHI levels for one or more racks at various flow field settings are compared to determine whether the SHI levels have changed at the different flow field settings. If the SHI levels have not changed for a particular rack, one or more of the flow field settings may be varied as indicated at step **606** and the SHI may be recalculated. For a particular rack, if the SHI levels have changed for different flow field settings, the controller **204** may determine the level to which the SHI has changed at step **612**. In addition, the controller **204** may correlate the change in SHI levels to the rack airflow at step **614**. By way of example, the controller **204** may access a database that is stored, for instance, in the memory **218**, that correlates various SHI level changes to rack airflows. The database may be configured, for instance, in the form of a look-up table.

At step **616**, based upon the correlation at step **614**, the controller **204** may output an evaluation of the airflows of one or more racks. In one regard, through knowledge of the airflows through the one or more racks, the racks may be reconfigured to generally enable better airflow through the one or more racks, which may yield greater optimization in the provisioning of cooling to those one or more racks.

As with the operational mode **300** in FIG. **3** and the operational mode **500** in FIG. **4**, a computational fluid dynamics (CFD) tool programmed to model airflow patterns for various data center configurations may be employed to perform the operational mode **600**. By way of example, some or all of the inputs, for instance, heat loads in the racks, volume flow rates of air supplied by one or more CRAC units, the layout of the data center, etc., may be manually inputted into the CFD tool. More particularly, the CFD tool may be programmed to calculate the SHI values for one or more racks based upon different CRAC flow settings and to calculate SHI values of the one or more racks based upon the different CRAC flow settings.

The CFD tool may also be programmed to determine variations in the SHI levels for the one or more racks in response to the different CRAC flow settings. The CFD tool may also be configured to evaluate the airflows through the one or more racks based upon the variations in the SHI levels. Consequently, a CFD tool employing the operational mode **600** may be used as a tool for evaluating the airflow characteristics through one or more racks. The airflow characteristics may be used, for instance, to [illegible]

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optimize provisioning of cooling to the one or more racks. In one respect, the influences of the one or more CRAC units may be used as a means for configuring the one or more racks such that airflow through the one or more racks is substantially optimized.

The operations set forth in the operational modes **300**, **500**, and **600** may be contained as utilities, programs, or subprograms, in any desired computer accessible medium. In addition, the operational modes **300**, **500**, and **600** may be embodied by computer programs, which can exist in a variety of forms both active and inactive. For example, it can exist as software program(s) comprised of program instructions in source code, object code, executable code or other formats. Any of the above can be embodied on a computer readable medium, which include storage devices and signals, in compressed or uncompressed form.

Exemplary computer readable storage devices include conventional computer system RAM, ROM, EPROM, EEPROM, and magnetic or optical disks or tapes. Exemplary computer readable signals, whether modulated using a carrier or not, are signals that a computer system hosting or running the computer program can be configured to access, including signals downloaded through the Internet or other networks. Concrete examples of the foregoing include distribution of the programs on a CD ROM or via Internet download. In a sense, the Internet itself, as an abstract entity, is a computer readable medium. The same is true of computer networks in general. It is therefore to be understood that any electronic device capable of executing the above-described functions may perform those functions enumerated above.

FIG. **7** illustrates an exemplary computer system **700** capable of performing various operations described hereinabove with respect to FIGS. **3**, **5**, and **6**. The computer system **700** may include, for example, the controller **204** and/or the computing device **126**. In this respect, the computer system **700** may be used as a platform for executing one or more of the functions described hereinabove.

The computer system **700** includes one or more controllers, such as a processor **702**. The processor **702** may be used to execute some or all of the steps described in the operational modes **300**, **500**, and **600**. Commands and data from the processor **702** are communicated over a communication bus **704**. The computer system **700** also includes a main memory **706**, such as a random access memory (RAM), where the program code for, for instance, the controller **204** and/or the controller of the computing device **126**, may be executed during runtime, and a secondary memory **708**. The secondary memory **708** includes, for example, one or more hard disk drives **710** and/or a removable storage drive **712**, representing a floppy diskette drive, a magnetic tape drive, a compact disk drive, etc., where a copy of the program code for the provisioning system may be stored.

The removable storage drive **710** reads from and/or writes to a removable storage unit **714** in a well-known manner. User input and output devices may include a keyboard **716**, a mouse **718**, and a display **720**. A display adaptor **722** may interface with the communication bus **704** and the display **720** and may receive display data from the processor **702** and convert the display data into display commands for the display **720**. In addition, the processor **702** may communicate over a network, e.g., the Internet, LAN, etc., through a network adaptor **724**.

It will be apparent to one of ordinary skill in the art that other known electronic components may be added or substituted in the computer system **700**. In addition, the computer system **700** may include a system board or blade used in a rack in a data center, a conventional "white box" server or computing device, etc. Also, one or more of the components in FIG. **7** may be optional (e.g., user input devices, secondary memory, etc.).

What has been described and illustrated herein is a preferred embodiment of the invention along with some of its variations. The terms, descriptions and figures used herein are set forth by way of illustration only and are not meant as limitations. Those skilled in the art will recognize that many variations are possible within the spirit and scope of the invention, which is intended to be defined by the following claims—and their equivalents—in which all terms are meant in their broadest reasonable sense unless otherwise indicated.

What is claimed is:

1. A method for evaluating one or more components in a data center, the method comprising:

detecting inlet and outlet temperatures of one or more heat dissipating devices;

detecting temperatures of air supplied by one or more computer room air conditioning (CRAC) units;

calculating indices of air re-circulation for the one or more heat dissipating devices based upon the detected inlet temperatures, outlet temperatures and supplied air temperatures;

varying a flow field setting of air delivered to the one or more heat dissipating devices;

determining whether the indices of air re-circulation has changed in response to the varied flow field settings; and

evaluating the one or more components based upon changes in the indices of air re-circulation for the one or more heat dissipating devices at the various flow field settings.

2. The method according to claim **1**, wherein the step of varying a flow field setting comprises varying at least one of a volume flow rate of air supplied by one or more CRAC units, at least one characteristic of air supplied through one or more vent tiles, and at least one characteristic of air returned through one or more return vent tiles.

3. The method according to claim **1**, further comprising:

comparing the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices; and

determining relationships between the indices of air re-circulation and the respective inlet temperatures of the one or more heat dissipating devices at the varied volume flow field settings.

4. The method according to claim **3**, further comprising:

plotting the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices based upon differing levels of flow field settings, wherein the step of determining relationships comprises determining whether the plots indicate that a nearly linear relationship exists between the plotted indices of air re-circulation and respective inlet temperatures of the one or more heat dissipating devices.

5. The method according to claim **4**, further comprising:

indicating that an infrastructure of the data center is substantially optimized in response to the plots indicating that a nearly linear relationship exists; and

indicating that the infrastructure of the data center is not substantially optimized in response to the plots indicating that a nearly linear relationship does not exist.

6. The method according to claim **1**, wherein the indices of air re-circulation are supply heat indices and are defined by the following equation:

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$$SHI = \left(\frac{T_{in} - T_{ref}}{T_{out} - T_{ref}}\right)$$

wherein, T_{in} and T_{out} are the inlet and outlet temperatures of one of the one or more heat dissipating devices, and T_{ref} denotes the supply air temperatures of one or more of the CRAC units.

7. The method according to claim **1**, further comprising:

designing a substantially optimized layout of the data center based upon the step of evaluating the one or more components.

8. The method according to claim **1**, further comprising:

determining various flow field settings;

comparing the indices of air re-circulation at the various flow field settings for at least one of the one or more heat dissipating devices; and

determining whether the indices of air re-circulation have changed for the various flow field settings for the at least one of the one or more heat dissipating devices.

9. The method according to claim **8**, wherein the flow field settings comprise volume flow rates of one or more CRAC units, and wherein the step of evaluating the one or more components comprises outputting an indication that the at least one of the one or more heat dissipating devices is not influenced by at least one of the one or more CRAC units in response to the indices of air re-circulation being substantially the same for the various volume flow rates for the at least one of the one or more heat dissipating devices; and

wherein the step of evaluating the one or more components comprises outputting an indication that the at least one of the one or more heat dissipating devices is influenced by at least one of the one or more CRAC units in response to the indices of air re-circulation changing for the various volume flow rates for the at least one of the one or more heat dissipating devices.

10. The method according to claim **9**, further comprising:

determining a level of influence of at least one of the one or more CRAC units in response to a determination that the at least one of the one or more heat dissipating devices is influenced by at least one of the one or more CRAC units.

11. The method according to claim **8**, further comprising:

varying one or more of the flow field settings in response to the indices of air re-circulation being substantially the same for the various one or more flow field settings for the at least one of the one or more heat dissipating devices;

determining the air re-circulation index of the at least one of the one or more heat dissipating devices; and

determining whether the indices of air re-circulation have changed for the various flow field settings for the at least one of the one or more heat dissipating devices.

12. The method according to claim **11**, further comprising:

determining the level of change in the air re-circulation index of at least one of the one or more heat dissipating devices in response to a determination that the air re-circulation index of the at least one of the one or more heat dissipating devices has changed;

correlating the level of change in the air re-circulation index of the at least one of the one or more heat dissipating devices to an airflow characteristic of the at least one of the one or more heat dissipating devices.

13. A computational fluid dynamics (CFD) tool for evaluating one or more components in a data center, said CFD tool comprising:

a modeling program configured to obtain inlet and outlet temperatures of one or more heat dissipating devices and temperatures of air supplied by one or more computer room air conditioning (CRAC) units based upon at least one of input by a user and through a calculation of airflow characteristics in the data center;

wherein the modeling program is further configured to calculate indices of air re-circulation of the one or more heat dissipating devices based upon the inlet and outlet temperatures of one or more heat dissipating devices and temperatures of air supplied by one or more CRAC units, the modeling program being further configured to calculate the indices of air re-circulation of the one or more heat dissipating devices at various flow field settings of air delivered to the one or more heat dissipating devices; and

wherein the modeling program is further configured to evaluate the one or more components based upon changes in the indices of air re-circulation of the one or more heat dissipating devices.

14. The CFD tool according to claim **13**, wherein the modeling program is further configured to compare the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices and to determine relationships between the indices of air re-circulation and the respective inlet temperatures of the one or more heat dissipating devices at the various flow field settings, said modeling program being further configured to plot the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices based upon the various flow field settings.

15. The CFD tool according to claim **14**, wherein the modeling program is further configured to determine whether a near linear relationship exists between the plotted indices of air re-circulation and respective inlet temperatures of the one or more heat dissipating devices at the various flow field setting, and wherein the modeling program is further configured to indicate that an infrastructure of the data center is substantially optimized in response to a determination that a near linear relationship exists and to indicate that the infrastructure of the data center is not substantially optimized in response to a determination that a nearly linear relationship does not exist.

16. The CFD tool according to claim **13**, wherein the modeling program is further configured to design a substantially optimized layout of the data center.

17. The CFD tool according to claim **13**, wherein the modeling program is further configured to determine various flow field settings, to compare the indices of air re-circulation at the various flow field settings for at least one of the one or more heat dissipating devices, and to determine whether the indices of air re-circulation have changed for the various volume flow field settings for the at least one of the one or more heat dissipating devices.

18. The CFD tool according to claim **17**, wherein the various flow field settings comprise various volume flow settings of one or more CRAC units, and wherein the modeling program is further configured to output an indication that the at least one of the one or more heat dissipating devices is not influenced by at least one of the one or more CRAC units in response to the indices of air re-circulation being substantially the same for the various volume flow rates for the at least one of the one or more heat dissipating devices, and to output an indication [illegible]

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the one or more heat dissipating devices is influenced by at least one of the one or more CRAC units in response to the indices of air re-circulation changing for the various volume flow rates for the at least one of the one or more heat dissipating devices.

19. The CFD tool according to claim **18**, wherein the modeling program is further configured to determine a level of influence of at least one of the one or more CRAC units in response to a determination that the at least one of the one or more heat dissipating devices is influenced by at least one of the one or more CRAC units.

20. The CFD tool according to claim **17**, wherein the modeling program is further configured to varying one or more of the flow field settings in response to the indices of air re-circulation being substantially the same for the various flow field settings for the at least one of the one or more heat dissipating devices, to determine the air re-circulation index of the at least one of the one or more heat dissipating devices; and to determine whether the indices of air re-circulation have changed for the various flow field settings for the at least one of the one or more heat dissipating devices.

21. The CFD tool according to claim **20**, wherein the modeling program is further configured to determine the level of change in the air re-circulation index of at least one of the one or more heat dissipating devices in response to a determination that the air re-circulation index of the at least one of the one or more heat dissipating devices has changed and to correlate the level of change in the air re-circulation index of the at least one of the one or more heat dissipating devices to an airflow characteristic of the at least one of the one or more heat dissipating devices.

22. A system for evaluating one or more components in a data center, said system comprising:

one or more heat dissipating devices having respective inlet and outlet temperature sensors;

one or more computer room air conditioning (CRAC) units having respective supply air temperature sensors; and

a controller configured to calculate indices of air re-circulation for the one or more heat dissipating devices based upon temperatures detected by the inlet and outlet temperature sensors and the supply air temperature sensors at various volume flow field settings of air delivered to the one or more heat dissipating devices, wherein the controller is further configured to evaluate the one or more components in the data center based upon changes in the air re-circulation indices.

23. The system according to claim **22**, wherein the controller is further configured to compare the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices and to determine relationships between the indices of air re-circulation and the respective inlet temperatures of the one or more heat dissipating devices at the various flow field settings, said controller being further configured to plot the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices based upon the various flow field settings.

24. The system according to claim **23**, wherein the controller is further configured to determine whether a near linear relationship exists between the plotted indices of air re-circulation and respective inlet temperatures of the one or more heat dissipating devices at the various flow field settings, and wherein the controller is further configured to indicate that an infrastructure of the data center is substantially optimized in response to a determination that a near linear relationship exists and to indicate that the infrastructure of the data center is not substantially optimized in response to a determination that a nearly linear relationship does not exist.

25. The system according to claim **22**, wherein controller is further configured to design a substantially optimized layout of the data center.

26. The system according to claim **22**, wherein the controller is configured to calculate the indices of air re-circulation through the following equation:

$$SHI = \left(\frac{T_{in} - T_{ref}}{T_{out} - T_{ref}} \right)$$

wherein, SHI is defined as a supply heat index, T_{in} and T_{out} are the inlet and outlet temperatures of one of the one or more heat dissipating devices, and T_{ref} denotes the supply air temperatures of one or more of the CRAC units.

27. The system according to claim **22**, wherein the controller is further configured to determine various flow field settings, to compare the indices of air re-circulation at the various flow field settings for at least one of the one or more heat dissipating devices, and to determine whether the indices of air re-circulation have changed for the various flow field settings for the at least one of the one or more heat dissipating devices.

28. The system according to claim **27**, wherein the various flow field settings comprise various volume flow rates of air supplied by one or more CRAC units, and wherein the controller is further configured to output an indication that the at least one of the one or more heat dissipating devices is not influenced by at least one of the one or more CRAC units in response to the indices of air re-circulation being substantially the same for the various volume flow rates for the at least one of the one or more heat dissipating devices, and to output an indication that the at least one of the one or more heat dissipating devices is influenced by at least one of the one or more CRAC units in response to the indices of air re-circulation changing for the various volume flow rates for the at least one of the one or more heat dissipating devices.

29. The system according to claim **28**, wherein the controller is further configured to determine a level of influence of at least one of the one or more CRAC units in response to a determination that the at least one of the one or more heat dissipating devices is influenced by at least one of the one or more CRAC units.

30. The system according to claim **27**, wherein the controller is further configured to varying one or more of the flow field settings in response to the indices of air re-circulation being substantially the same for the various flow field settings for the at least one of the one or more heat dissipating devices, to determine the air re-circulation index of the at least one of the one or more heat dissipating devices; and to determine whether the indices of air re-circulation have changed for the various flow field settings for the at least one of the one or more heat dissipating devices.

31. The system according to claim **30**, wherein the controller is further configured to determine the level of change in the air re-circulation index of at least one of the one or more heat dissipating devices in response to a determination that the air re-circulation index of the at least one of the one or more heat dissipating devices has changed and to correlate the level of change in the air re-circulation [illegible]

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at least one of the one or more heat dissipating devices to an airflow characteristic of the at least one of the one or more heat dissipating devices.

32. A system for evaluating one or more components in a data center, said system comprising:

means for detecting inlet and outlet temperatures of one or more heat dissipating devices;

means for detecting temperatures of air supplied by one or more computer room air conditioning (CRAC) units;

means for calculating indices of air re-circulation for the one or more heat dissipating devices at various flow field settings of air delivered to the one or more heat dissipating devices; and

means for evaluating the one or more components based upon the calculated indices of air re-circulation at the various flow field settings.

33. The system according to claim **32**, wherein the means for calculating comprises means for comparing the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices and means for determining relationships between the indices of air re-circulation and the respective inlet temperatures of the one or more heat dissipating devices at the varied flow field settings.

34. The system according to claim **32**, further comprising:

means for designing a substantially optimized layout of the data center based upon the step of evaluating the one or more components.

35. The system according to claim **32**, further comprising:

means for determining volume flow rates of air supplied by the one or more CRAC units;

means for comparing the indices of air re-circulation at the various volume flow rates of air supplied by the one or more CRAC units for at least one of the one or more heat dissipating devices;

means for determining whether the indices of air re-circulation have changed for the various volume flow rates for the at least one of the one or more heat dissipating devices; and

means for outputting at least one of an indication and a level of influence of at least one of the one or more CRAC units over at least one of the one or more racks.

36. The system according to claim **32**, further comprising:

means for varying one or more of the flow field settings in response to the indices of air re-circulation being substantially the same for the various flow field settings for the at least one of the one or more heat dissipating devices;

means for determining the air re-circulation index of the at least one of the one or more heat dissipating devices;

means for determining whether the indices of air re-circulation have changed for the various flow field settings for the at least one of the one or more heat dissipating devices;

means for determining the level of change in the air re-circulation index of at least one of the one or more heat dissipating devices in response to a determination that the air re-circulation index of the at least one of the one or more heat dissipating devices has changed; and

means for correlating the level of change in the air re-circulation index of the at least one of the one or more heat dissipating devices to an airflow characteristic of the at least one of the one or more heat dissipating devices.

37. A computer readable storage medium on which is embedded one or more computer programs, said one or more computer programs implementing a method for evaluating one or more components in a data center, said one or more computer programs comprising a set of instructions for:

detecting inlet and outlet temperatures of one or more heat dissipating devices;

detecting temperatures of air supplied by one or more computer room air conditioning (CRAC) units;

calculating indices of air re-circulation for the one or more racks at various flow field settings of air delivered to the one or more heat dissipating devices; and

evaluating the one or more components based upon the calculated indices of air re-circulation at the various flow field settings.

38. The computer readable storage medium according to claim **37**, said one or more computer programs further comprising a set of instructions for:

comparing the indices of air re-circulation with respective inlet temperatures of the one or more heat dissipating devices; and

determining relationships between the indices of air re-circulation and the respective inlet temperatures of the one or more heat dissipating devices at the varied flow field settings.

39. The computer readable storage medium according to claim **37**, said one or more computer programs further comprising a set of instructions for:

designing a substantially optimized layout of the data center based upon the step of evaluating the one or more components.

40. The computer readable storage medium according to claim **37**, said one or more computer programs further comprising a set of instructions for:

determining volume flow rates of air supplied by the one or more CRAC units;

comparing the indices of air re-circulation at the various volume flow rates of air supplied by the one or more CRAC units for at least one of the one or more heat dissipating devices;

determining whether the indices of air re-circulation have changed for the various volume flow rates for the at least one of the one or more heat dissipating devices; and

outputting at least one of an indication and a level of influence of at least one of the one or more CRAC units over at least one of the one or more heat dissipating devices.

41. The computer readable storage medium according to claim **37**, said one or more computer programs further comprising a set of instructions for:

varying one or more of the flow field settings in response to the indices of air re-circulation being substantially the same for the various flow field settings for the at least one of the one or more heat dissipating devices;

determining the air re-circulation index of the at least one of the one or more heat dissipating devices;

determining whether the indices of air re-circulation have changed for the various flow field settings for the at least one of the one or more heat dissipating devices;

determining the level of change in the air re-circulation index of at least one of the one or more heat dissipating devices in response to a determination that the air re-circulation index of the at least one of the one or more heat dissipating devices has changed; and

correlating the level of change in the air re-circulation index of the at least one of the one or more heat dissipating devices to an airflow characteristic of the at least one of the one or more heat dissipating devices.

* * * * *

EXHIBIT E

US007339490B2

(12) **United States Patent**
Moore et al.

(10) **Patent No.: US 7,339,490 B2**
(45) **Date of Patent: Mar. 4, 2008**

(54) **MODULAR SENSOR ASSEMBLY**

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(73) Assignee: **Hewlett-Packard Development Company, L.P.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 663 days.

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(51) **Int. Cl.**

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G08B 1/08	(2006.01)
H04Q 7/00	(2006.01)
G06F 1/16	(2006.01)
H05K 5/00	(2006.01)

(52) **U.S. Cl.** **340/693.5**; 340/539.27; 361/686

(58) **Field of Classification Search** 340/693.5–693.12, 438, 449, 500–539.32, 340/601–604, 628, 635–656, 3.1, 3.5–3.54, 340/3.7–3.9, 825.36–825.78, 286.01–286.05; 361/683, 686–727; 454/193

See application file for complete search history.

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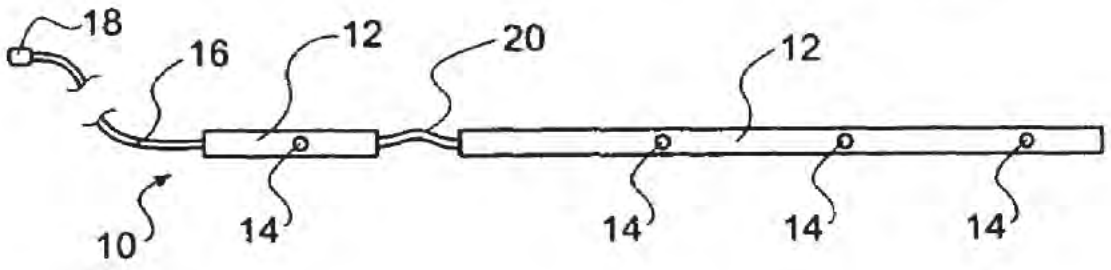
* cited by examiner

Primary Examiner—Benjamin C. Lee
Assistant Examiner—Jennifer Mehmood

(57) **ABSTRACT**

A modular sensor assembly for sensing conditions at a computer rack, such as environmental conditions. The sensor assembly includes an elongate flexible body, configured to attach to a computer rack, with a plurality of addressable sensors, disposed along the body and interconnected to a common connector wire. A connector wire lead is provided to interconnect the connector wire to a central system configured to receive and interpret data from the plurality of sensors relating to conditions associated with the computer rack.

28 Claims, 4 Drawing Sheets



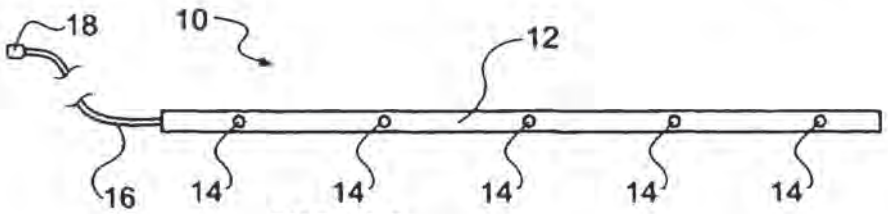


FIG 1A

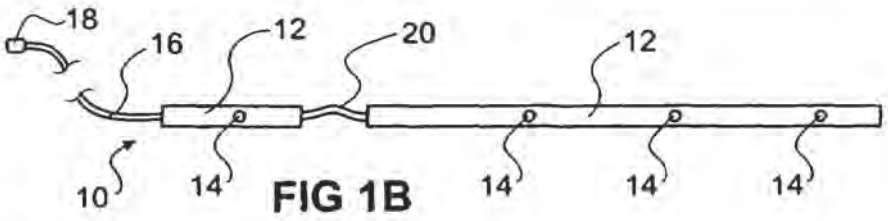


FIG 1B

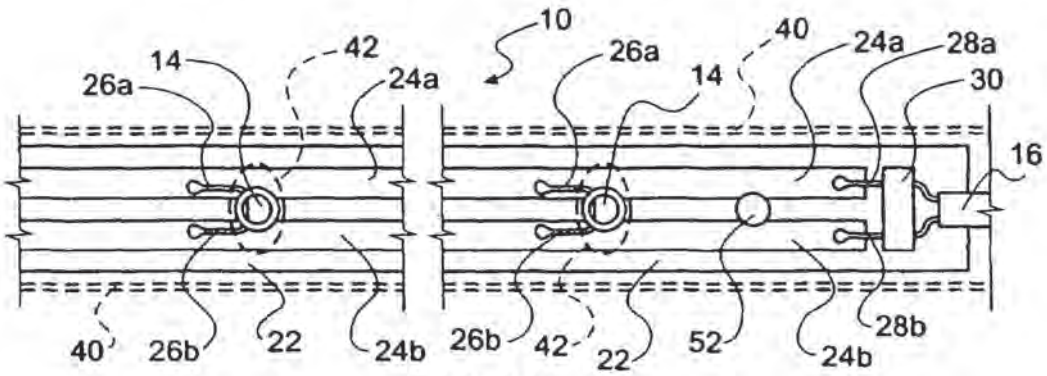


FIG 2A

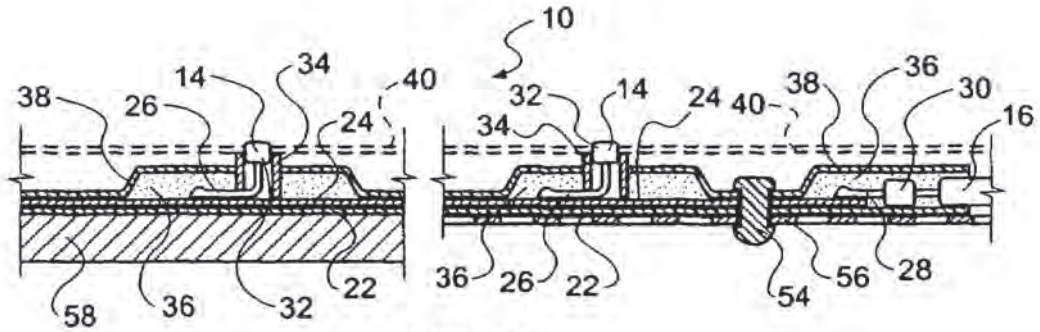


FIG 2B

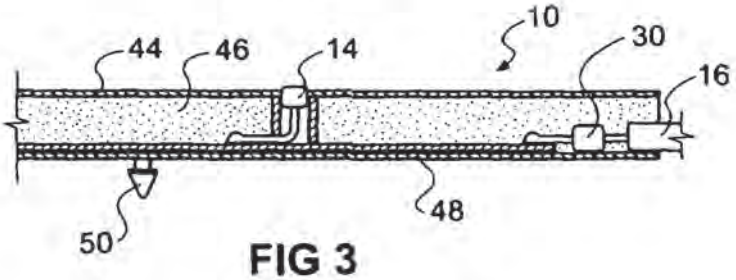


FIG 3

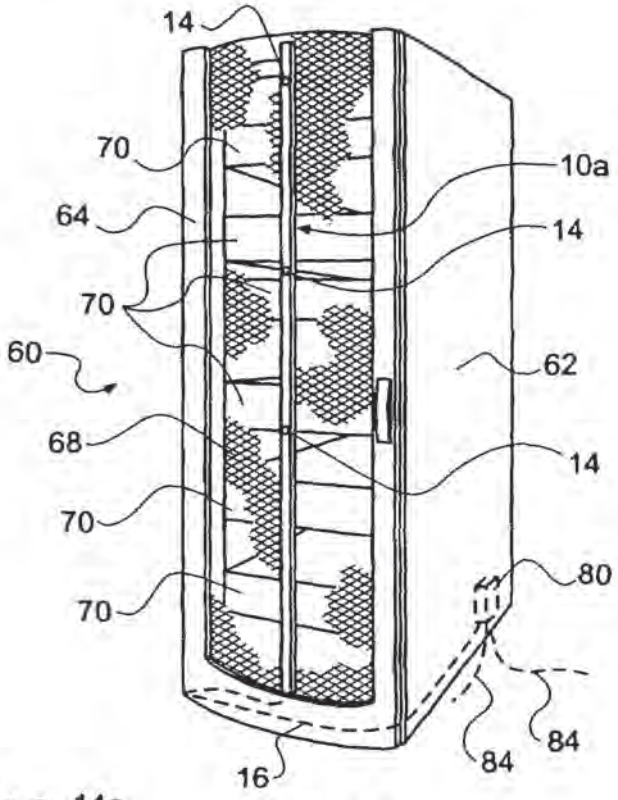

14
70
10a
64
14
70
62
60
68
14
70
80
70
84
84
16

FIG 4

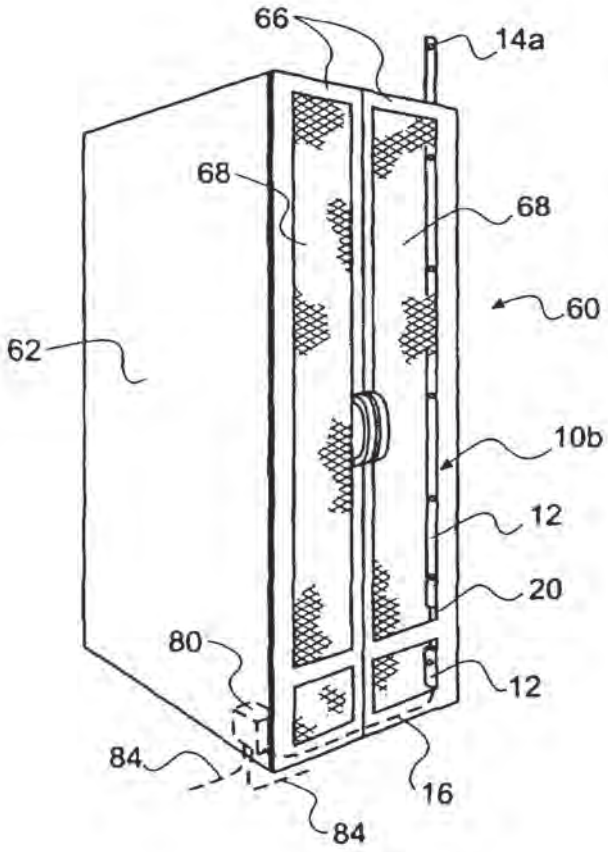

66
14a
68
68
60
62
10b
12
20
80
12
84
16
84

FIG 5

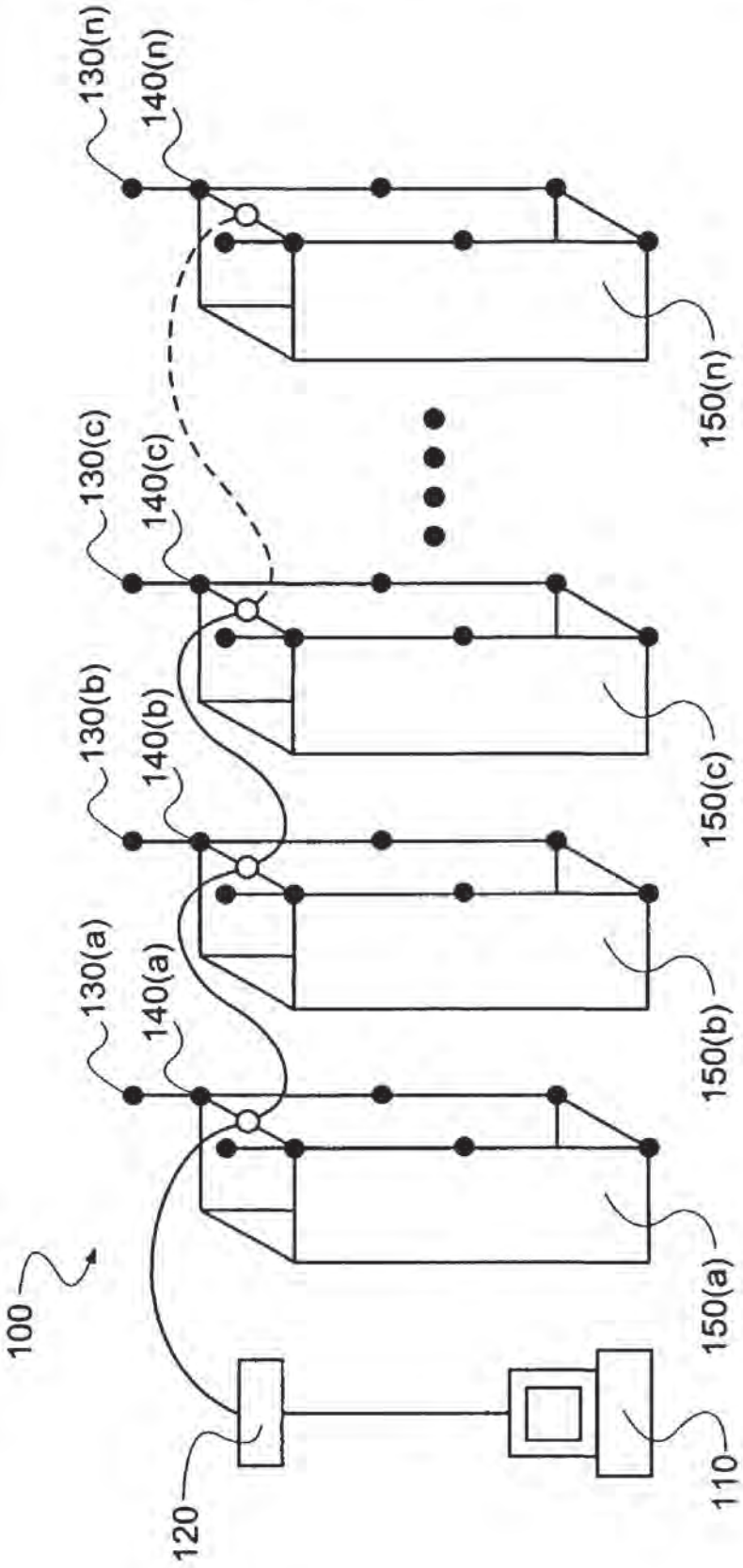

130(n)
140(n)
150(n)
130(c)
140(c)
150(c)
130(b)
140(b)
150(b)
130(a)
140(a)
150(a)
100
120
110

FIG 6

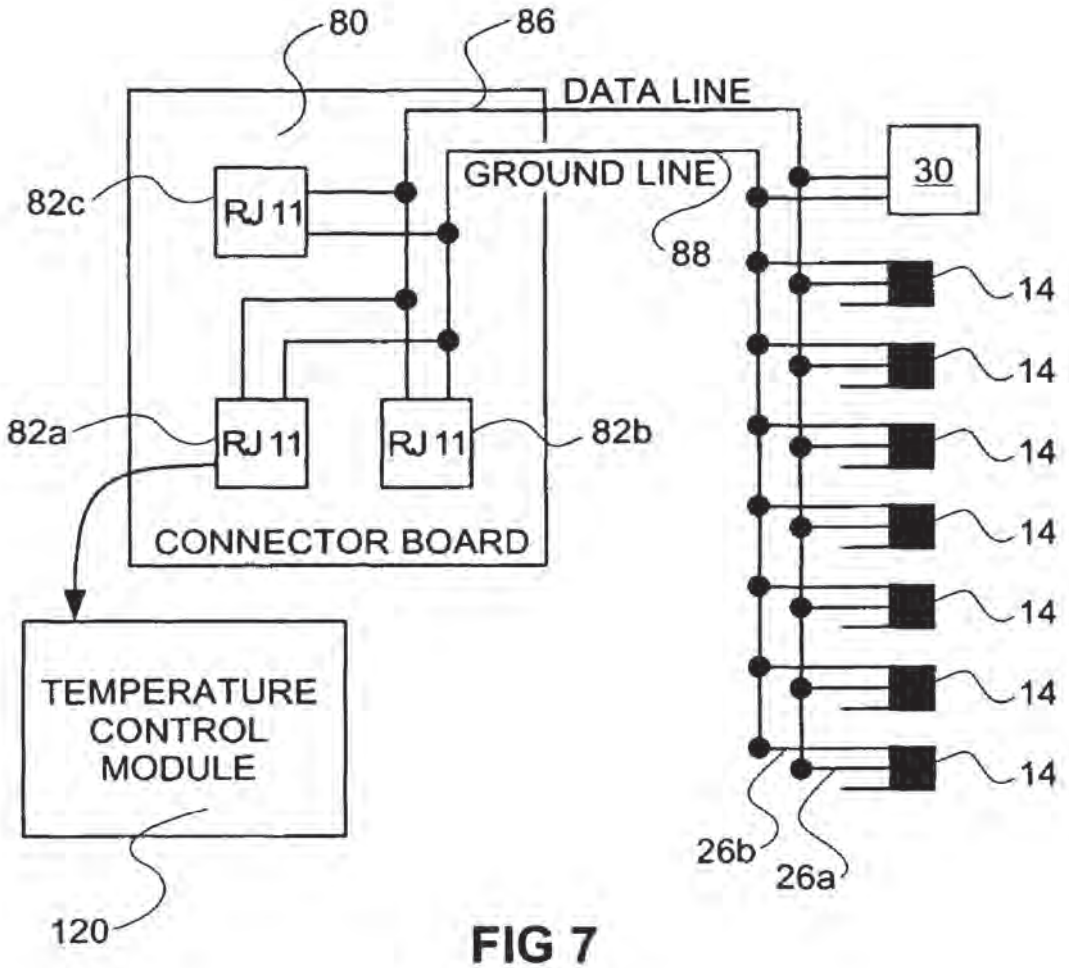

80
86
DATA LINE
GROUND LINE
88
30
82c
RJ 11
14
14
14
14
14
14
14
82a
RJ 11
RJ 11
82b
CONNECTOR BOARD
TEMPERATURE CONTROL MODULE
120
26b
26a

FIG 7

MODULAR SENSOR ASSEMBLY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to a sensor system for monitoring conditions in a data center.

2. Related Art

A data center may be defined as a location, e.g., a room, that houses numerous printed circuit (PC) board electronic systems arranged in a number of racks. A standard rack may be defined as an Electronics Industry Association (EIA) enclosure, 78 in. (2 meters) high, 24 in. (0.61 meter) wide and 30 in. (0.76 meter) deep. Standard racks may be configured to house a number of PC boards, e.g., about forty (40) PC server systems, with some existing configurations of racks being designed to accommodate up to 280 blade systems. The PC boards typically include a number of components, e.g. processors, micro-controllers, high speed video cards, memories, and the like, that dissipate relatively significant amounts of heat during the operating of the respective components. For example, a typical PC board comprising multiple microprocessors may dissipate approximately 250 W of power. Thus, a rack containing forty (40) PC boards of this type may dissipate approximately 10 KW of power.

The power required to remove the heat dissipated by the components in the racks is generally equal to about 10 percent of the power needed to operate the components. However, the power required to remove the heat dissipated by a plurality of racks in a data center is generally equal to about 50 percent of the power needed to operate the components in the racks. The disparity in the amount of power required to dissipate the various heat loads between racks and data centers stems from, for example, the additional thermodynamic processing needed in the data center to cool the air.

In one respect, racks are typically cooled with fans that operate to move cooling fluid, e.g., air, across the heat dissipating components; whereas, data centers often implement reverse power cycles to cool heated return air. The additional work required to achieve the temperature reduction, in addition to the work associated with moving the cooling fluid in the data center and the condenser, often add up to the 50 percent power requirement. As such, the cooling of data centers presents problems in addition to those faced with the cooling of racks.

Conventional data centers are typically cooled by operation of one or more air conditioning units. The compressors of the air conditioning units typically require a minimum of about thirty (30) percent of the required cooling capacity to sufficiently cool the data centers. The other components, e.g., condensers, air movers (fans), etc., typically require an additional twenty (20) percent of the required cooling capacity. As an example, a high density data center with 100 racks, each rack having a maximum power dissipation of 10 KW, generally requires 1 MW of cooling capacity.

Air conditioning units with a capacity of 1 MW of heat removal generally require a minimum of 30 KW input compressor power in addition to the power needed to drive the air moving devices, e.g., fans, blowers, etc. Conventional data center air conditioning units do not vary their cooling fluid output based on the distributed needs of the data center. Instead, these air conditioning units generally operate at or near a maximum compressor power even when the heat load is reduced inside the data center.

The substantially continuous operation of the air conditioning units is generally designed to operate according to a worst-case scenario. That is, cooling fluid is supplied to the components at around 100 percent of the estimated cooling requirement. In this respect, conventional cooling systems often attempt to cool components that may not need to be cooled. Consequently, conventional cooling systems often incur greater amounts of operating expenses than may be necessary to sufficiently cool the heat generating components contained in the racks of data to the components at around 100 percent of the estimated cooling requirement. In this respect, conventional cooling systems often attempt to cool components that may not need to be cooled. Consequently, conventional cooling systems often incur greater amounts of operating expenses than may be necessary to sufficiently cool the heat generating components contained in the racks of data centers.

Consequently, the inventors have developed systems for collecting temperature data from data centers so that the computing equipment can be cooled based on actual cooling requirements. Such systems can include large numbers of temperature sensors to provide detailed temperature information from many different locations within the data center, allowing a cooling system to provide cooling only where it is needed, and only to the extent actually needed by the electronic systems.

Unfortunately, the traditional approach to sensing large numbers of temperatures distributed throughout a large volume is costly and cumbersome. Typically thermistor or thermocouple sensors are used. These sensors require that a continuous wire be installed from the sensor location to a central instrument where temperature readings are made. Each sensor must be connected to the instrument with its own wire. The wire involved must meet special manufacturing and installation characteristics to provide an accurate result. This results in a very costly and cumbersome installation with large bundles of expensive wire spread throughout the measurement environment. The cost of these methods can be quite high.

A typical temperature data acquisition system could include a central datalogger which contains a switch matrix and analog-to-digital converter, with cold-junction compensation for thermocouple input. Such systems are available that are capable of measuring 60 thermocouple temperature sensors, though this is not a limit. Some systems expand to accommodate a thousand sensors. Unfortunately, this sort of system requires installation of a continuous thermocouple wire from each measurement point to the instrument. Thermocouple wire is a specialized material that must be installed to special requirements for accurate results. Each conductor is a different material, and all junctions must maintain material integrity from sensor to instrument. This requires special connectors and installation procedures.

Industrial versions of this type of equipment are also available, and present similar disadvantages. One such concept is the use of separate "transmitters" at each measurement point that convert from a thermocouple to a network protocol at each measurement point. This is a very costly approach, and requires that power be supplied at each measurement point. Additionally, any installation using traditional techniques would require custom mounting of sensors in the field. This can lead to a visually unappealing installation. Field installation also often results in wire routing that leaves sensor wire vulnerable to damage during operation of the data center.

Accordingly, it has been recognized that it would be advantageous to develop a distributed [illegible]

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that is simple to install on new or existing equipment rack systems, and that provides a low cost sensor assembly for deploying multiple sensors over a widely distributed area.

SUMMARY OF THE INVENTION

The invention advantageously provides a modular sensor assembly for sensing conditions at a computer rack. The sensor assembly includes an elongate flexible body, configured to attach to a computer rack, with a plurality of addressable sensors, disposed along the body and interconnected to a common connector wire. A connector wire lead is provided to interconnect the connector wire to a central system configured to receive and interpret data from the plurality of sensors relating to conditions associated with the computer rack.

Additional features and advantages of the invention will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a plan view of one embodiment of a sensor assembly.

FIG. **1**B is a plan view of an alternative embodiment of a sensor assembly.

FIG. **2**A is a top, partially disassembled view of a temperature sensor, showing various alternative configurations.

FIG. **2**B is a side, cross-sectional view of the temperature sensor of FIG. **2**A.

FIG. **3** is a side, cross-sectional view of an alternative embodiment of a sensor assembly.

FIG. **4** is a front perspective view of one embodiment of an electronics rack configured with a sensor assembly.

FIG. **5** is a rear perspective view of one embodiment of an electronics rack configured with a sensor assembly.

FIG. **6** is a schematic illustration of one embodiment of a rack system provided with sensors.

FIG. **7** shows a sensor connection scheme that can be implemented using the sensor assembly shown herein.

DETAILED DESCRIPTION

Reference will now be made to the exemplary embodiments illustrated in the drawings, and specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Alterations and further modifications of the inventive features illustrated herein, and additional applications of the principles of the invention as illustrated herein, which would occur to one skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of the invention.

Depicted in FIGS. **1**A and **1**B are two embodiments of a modular sensor assembly **10**. The sensor assembly generally comprises an elongate flexible body **12**, with a plurality of sensors **14** disposed along it. A connector wire **16**, such as flat phone-type wire, extends from one end of the body, and includes a connector **18**, such as a telephone-type modular connector, for allowing the connector wire to be interconnected to a computer network, so that temperature or other data can be communicated from the sensors to the network. The sensor assembly can be substantially continuous as in FIG. **1**A, or can comprise more than one sensor segment interconnected by an intermediate connector wire **20**, as

shown in FIG. **1**B. While the sensor assembly is depicted as a linear device, other topologies can also be used to deploy sensors.

Depicted in FIGS. **2**A and **2**B are views showing the internal structure of the sensor assembly **10**. The sensor assembly generally comprises several layers of material laminated together to form a rugged but flexible assembly. The sensor assembly includes a base layer **22**, to which the other components are attached. The base layer can be a 0.010" thick plastic strip 0.75" wide. Rugged plastic tape could also be used for the base layer, for example.

Disposed atop the base layer **22** are multiple flat conductors **24**. The conductors can be conductive tapewire, such as copper foil tape with an adhesive backing. Conductive foil or flex circuit tape can be used, such as copper tape foil CK1017 from Cir-Kit Concepts Inc. While two flat conductors are shown in the depicted embodiment, the sensor assembly is not limited to two, for reasons that are discussed below. Of the two flat conductors shown, one conductor **24***a* represents a data line and the other conductor **24***b* represents a ground line.

A sensor device **14** is attached (e.g. soldered) to the flat conductors **24** via its leads **26**. There are a variety of sensor types and sensor products that can be used. One type of temperature sensor that the inventors have employed is a Dallas Semiconductor/Maxim integrated circuits DS18S20-PAR sensor. The sensor assembly can also be used to deploy other digital transducers or sensors with similar connectivity requirements but differing functionalities, such as transducers and sensors for detecting fluid pressure, fluid velocity, humidity, occupancy, light, smoke, door condition, etc. Multiple or redundant conductor assemblies can be developed to address connectivity requirements of a wide variety of transducers and provide customization (or upgrades). The sensor assembly can also be used beyond the rack assembly, for other non-rack related sensors like pressure transducers inside a plenum or temperature sensors for vents.

Each sensor **14** includes at least two connection leads **26**. One lead **26***a* serves as a data connection lead while the other lead **26***b* is a ground connection lead. The data connection lead connects the sensor to a computer controller **110**, shown in FIG. **6**. The ground connection lead and the data connection lead can be configured either in one long wire pair, as shown, with multiple sensors in parallel.

Power for the sensor **14** is parasitically drawn from the data line **24***a*. Specifically, the sensor includes an internal capacitor, which draws power and charges during data line inactivity. Alternatively, a sensor without an internal capacitor could be used. Such a sensor could include three leads, one of which would be connected to a power supply line (not shown) that would be separate from the data and ground lines. Thus, such a system would require a third conductor line, in addition to the data line **24***a* and ground line **24***b* shown in the figures.

In the embodiment shown, the sensor **14** is configured to measure ambient temperature a small distance (e.g. 15 mm) from the sensor assembly, and convert the temperature reading into a digital signal. One advantage of implementing this type of sensor is that a central instrument is not needed. Each sensor is capable of independently converting physical temperature data to transmittable digital data. This eliminates the need to carry sensitive analog signals from point to point. The digital data provided by the sensor can be protected by CRC algorithms that prevent distortion of the data.

The connector wire **16** is a multiple conductor wire. In the depicted embodiment, the connector wire has six

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conductors **28***a*, **28***b*, the ends of which are connected (e.g. soldered) to the ends of the flat conductors **24** to provide connectivity to the sensing network. One conductor **28***a* is the data line, and the other conductor **28***b* is the ground line. It will be apparent that where the sensor assembly includes more than two flat conductors, the connector wire will also include more than two corresponding conductors.

It will be apparent that there must be some way to identify and distinguish the physical location of each sensor in the system. This can be done in several ways. In one configuration, shown in FIG. **2**A and **2**B, attached to the conductor wire **16** at the base of the sensor assembly **10** is a memory device **30**. This memory device is configured to contain configuration and identification information related to the sensors **14** that are attached to that particular sensor assembly. The memory device can be an EEPROM device that includes a memory table with the identification information for each sensor. Specifically, in one embodiment, each Dallas Semiconductor DS18S20-PAR sensor has a unique factory-assigned 64 bit identification code or address. The memory device can be configured to retain in memory the addresses of each sensor disposed downstream, so as to speed the collection of data. This configuration advantageously provides a two-conductor physical interface with a large address space.

However, the system is not limited to this configuration. As an alternative, the identification of each sensor **14** can be prescribed with a much smaller address, such as that used by I2C devices. However, this configuration requires at least four conductors on the sensor assembly, and also requires wiring (e.g. printed circuits) with passive components at each sensor for retaining address settings. Alternatively, a user-defined identification code for each sensor (rather than a factory-assigned code) can be prescribed and recorded in the memory device **30**, the memory device being factory-set with the user-defined identification codes. As still another alternative, the central computer (**110** in FIG. **6**) can be programmed with each sensor address in order to accurately collect and interpret the sensor data.

The sensor assembly **10** can include a number of other features for ruggedness, durability, and convenience. In the embodiment shown in FIGS. **2**A and **2**B, a first protective cover **32**, such as a short section of 1/16" shrink tubing, is provided to cover the leads **26** of the sensor **14**, and a second protective cover **34**, such as a short section of 1/4" shrink tubing, is provided to cover the entire sensor, leaving about 2 mm of the sensor protruding. A small piece of cushioning material **36**, such as 1/8" thick double faced foam tape, is disposed around the second protective cover around the sensor, and a similar piece of cushioning material **36** is provided around the connector wire **16** and memory device **30**. These protective covers, cushioning material, and similar features serve as strain relief and protective coverings for the various components, helping to prevent damage to the sensor, the memory device, the conductor wire, and related electrical connections. It will be apparent, however, that the functions of these features could be performed by different sorts of structures, and that the body of the sensor assembly could be configured in a variety of different ways.

A top layer **38** of plastic or other material is provided over the top of the sensor assembly to cover and protect it. This top layer can be of the same material and same basic size as the base layer **22** described above. An adhesive or adhesive layer, such as thin double-sided adhesive tape (not shown), can be applied to the top of the flat conductors **24** to adhere the top layer to the base layer and flat conductors between the sections of cushioning material **36**.

The sensor assembly **10** can be disposed within a molding or other elongate protective structure, such as a channel **40** as depicted in FIG. **2**. This channel includes multiple openings **42** to allow the individual sensors **14** of the sensor assembly to protrude through to the outer environment. The molding or channel can be of aluminum, plastic, or any other suitable material. The molding can provide a decorative trim piece for the equipment rack, and can be configured to attach to the inside or outside of the rack.

Other configurations and materials can also be used for the sensor assembly. For example, as shown in FIG. **3**, a semi-rigid top layer **44** can be adhered directly to a continuous layer **46** of internal cushioning material, rather than the small segments of cushioning material **36** shown in FIG. **2**. This top layer can be of plastic, aluminum, or other material comprising a decorative molding or trim piece. Likewise, a bottom layer **48** disposed below the base layer **22** can be of a comparable material, and include mounting structure, such as an integral snap rivet **50** to accommodate mounting of the sensor assembly to a computer rack.

Depicted in FIG. **2** are some other features related to the use and installation of the sensor assembly **10**. The sensor assembly can include one or more holes **52** (FIG. **2**A) through which a snap rivet **54** (FIG. **2**B) or other connector device can be inserted to attach the sensor assembly to a support structure **56**, such as a perforated panel, mounting track, or other structure associated with a computer rack. Additionally, viewing the left side of FIG. **2**B, it can be desirable to install the sensor assembly in a location where other support is not available, as described below. In such cases, a rigid or semi-rigid support member **58** can be mounted to the base layer **22** of the sensor assembly to provide the needed strength and support.

Depicted in FIGS. **4** and **5** are front and rear perspective views of one embodiment of an electronics rack **60** configured with sensor assemblies **10**. There are a variety of equipment racks that are commercially available, and the application of the sensor assembly is not limited to compatibility with just one variety. The rack can be configured in various ways, and is not limited to the configuration shown. The rack shown in the drawings generally comprises an upright body **62**, with an access door **64** on its front (FIG. **3**) and a pair of access doors **66** on the back. The front and rear doors include a screen, mesh, or perforated panel **68** that allows air to flow through, and also allows users to view components and hardware inside.

The computer rack **60** houses a plurality of components **70**, e.g., processors, micro-controllers, high speed video cards, memories, semi-conductor devices, and the like. The components may be elements of a plurality of subsystems (not shown), e.g., computers, servers, etc. In the performance of their electronic functions, the components, and therefore the subsystems, generally dissipate relatively large amounts of heat. Because computer rack systems have been generally known to include upwards of forty (40) or more subsystems, they may need substantially large amounts of cooling resources to maintain the subsystems and the components generally within a predetermined operating temperature range. Additionally, the temperature of cooling air supplied by a data center cooling system is likely to vary based on distance between the cooling equipment and the computer rack. Accordingly, temperature readings associated with the operation of the computer rack are gathered at multiple points in the vertical and horizontal directions.

The sensor assemblies **10** can be configured to fit onto installation features built into the rack **60**. For example, the front sensor assembly **10***a*, shown in [illegible]

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sensor assembly installed on a cosmetically pleasing trim strip, and is mounted on the perforated panel **68** of the front door **64** of the rack. The sensor assembly includes three sensors **14**, for obtaining a measurement of inlet air temperature from near the bottom to the top of the rack. If the rack does not include a front door, the sensor assembly can be installed on or in a trim strip at an edge of the front of the rack.

As shown in FIG. **5**, the rear sensor assembly **10***b* can be designed to mount within the rear cavity of the rack **60**, inside one of the rear doors **66**. Alternatively, the sensor assembly could be configured to mount on the rear mounting channels. Cosmetic appearance is not as important in the rear of the rack, but mounting flexibility is. There are typically many obstructions in this area, and mounting of a continuous sensor assembly may be difficult. For this reason the rear sensor assembly **10***b* shown is configured like that of FIG. **1**B, comprising more than one sensor section **12**, interconnected by a flexible intermediate connector wire **20**. The flat sensor sections make installation simple, and the intermediate connector wire provides for routing around obstacles, such as the cross bar of the rack door, etc.

It is also notable that the rear sensor assembly **10***b* includes an overhead sensor **14***a* that is disposed on a portion of the sensor assembly extending above the rack **60**. This configuration can be accommodated in various ways. For example, where the sensor assembly is disposed inside the rear doors **66**, the overhead portion of the sensor assembly can be a discontinuous portion that is connected to the remainder of the assembly via a connector wire. This wire can extend unobtrusively between the adjacent door and the body of the rack. The overhead portion of the sensor assembly can be attached to additional support structure, such as an upright rod, that is associated with the rack. Alternatively, the overhead portion of the sensor assembly can include a support member like the support member **58** shown in FIG. **2**B. Other configurations are also possible to provide for overhead sensors.

The sensor assemblies **10** are designed to facilitate easy mounting on an equipment rack, either at the factory before shipment to the customer, or at the customer site for installation as an option. This is accomplished by building mounting features into the rack that will accommodate the sensor assembly. These features can be in the form of a channel or series of holes in the surface of the rack (designed to receive snap rivets or other connectors), and are designed to fit mounting provisions on the rack. When a sensor assembly is not installed at a given location that is configured to receive one, a compatible blank trimming strip can be installed at that location to cover the exposed mounting locations. In this way a cosmetically appealing appearance can be maintained whether or not the sensor assembly is installed.

Mounting point features designed into equipment racks make installation of the sensor assembly a simple process. The sensor assemblies may also be retrofitted onto racks without mounting features by using adhesive to connect the sensor body **12** to the rack, such as by using double-sided adhesive tape.

The sensor assembly solves some of the manufacturing and installation problems for networked environmental sensors. It provides a system for deploying a widely distributed sensor network with simple parallel wiring. The labor-intensive and costly installation process of traditional temperature measurement is replaced by an unobtrusive, easily installed assembly. Separate specialized electrical connections are replaced by a single parallel circuit of standard telecommunications-grade wiring. Advantageously, the sensor assembly provides broad sensor coverage in an easily installed package. The sensor assembly can be produced at a low cost, and is easily manufactured using existing assembly techniques.

A cost effective network of digital sensors has many advantages over traditional methods. Systems sometimes referred to as "smart cooling" systems have been developed to provide a networked environmental monitor comprising a plurality of temperature sensors, located at various locations throughout a data center, to dynamically collect temperature data at various locations within the data center. By dynamically collecting temperature data at various locations within the data center, the cooling resources of the data center can be allocated based on the actual cooling requirements of the data center. As a result, substantial savings in operational costs related to the operation of the data center cooling resources is possible.

The sensor assembly shown herein is compatible with "smart cooling" systems and their associated temperature data collection system. The various elements and aspects of a networked environmental monitoring system for collecting and using temperature data from a large number of sensors in a data center are depicted in FIGS. **6-7**. In the context of "smart cooling" it is necessary to deploy a number of sensors on the front and rear surfaces of computer equipment racks. Provided in FIG. **6** is an illustration of one embodiment of a system **100** for collecting temperature data that could incorporate the sensor assembly disclosed herein. The installation in which the temperature collection system is illustrated is a data center, though it will be apparent that the sensor assembly is not limited to use in data centers. The temperature collection system includes a central computer system **110**, a temperature-collection module **120**, a plurality of computer racks **150**(*a . . . n*) wherein each of the plurality of computer racks includes a plurality of temperature sensors **130**(*a . . . n*) and a connector board **140**(*a . . . n*). The temperature-collection module is coupled to at least one of the connector boards, and to the central computer system.

The method of collecting temperature data using the system depicted in FIG. **6** involves the steps of coupling a plurality of sensors to at least one rack of systems. The plurality of sensors are then interconnected to the central computer system. The central computer system then collects temperature data from each of the plurality of sensors, and controls the data center cooling system in accordance with that temperature information.

The computer system **110** may be any of a variety of different types, such as a notebook computer, a desktop computer, an industrial personal computer, an embedded computer, etc. The computer system includes a processor and various other components such as a user interface (e.g. keyboard, mouse, voice recognition system, etc.), and an output device (e.g. a computer monitor, a television screen, a printer, etc.), depending upon the desired functions of the computer system. A communications port can also be coupled to the processor to enable the computer system to communicate with an external device or system, such as a printer, another computer, or a network.

The computer system **110** may also be utilized in conjunction with a distributed computing environment where tasks are performed by remote processing devices that are linked through a communications network. Examples of such distributed computing environments include local area networks of an office, enterprise-wide computer networks, and the Internet. Additionally, the networks could communicate via wireless means or any of a variety of communication means.

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Referring back to FIG. **6**, each of the plurality of computer racks **150**(*a* . . . *n*) includes a plurality of temperature sensors **130**(*a* . . . *n*). Since the temperature profile of air throughout the system **100** is typically non-uniform, multiple sensors are implemented to capture temperature data at multiple points. In order to get an accurate profile of temperature or other conditions, any number of sensors can be deployed on or near each computer rack. In the configuration shown in FIG. **6**, each rack in the data center is shown having 3 sensors on the front and 3 sensors on the rear of the rack case, with two additional overhead sensors disposed above the body of the rack. These sensors provide inputs into the control algorithms employed by "smart cooling" to manage the environment within the datacenter. However, other configurations can also be used. For example, the front sensor assembly shown in FIG. **4** includes three sensors on the center of the door of the rack, with no overhead sensors. The rear sensor assembly shown in FIG. **5** includes six sensors disposed inside the rear door of the rack, with an additional overhead sensor disposed above the rack. Other configurations are also possible.

Each sensor assembly **10** includes a connector wire **16** with a mechanical connector **18** at its end. Associated with each rack **60** is a connector board **80**, like the connector board **140** shown in FIG. **6**. The connector wire from each sensor assembly connects to the connector board associated with the rack. In one simple configuration, the connector board needs no power and serves as a connection point for each of the plurality of sensors, and as a means for transmitting collected temperature data to the temperature collection module. FIG. **7** shows an example of a connector board and connection scheme that can be utilized in conjunction with various embodiments of the sensor assembly. The connector board includes at least two input ports **82**. These first input ports are configured to connect, via the connector, to a ground line and a data line associated with a connector wire.

The input ports **82** can be RJ-11 phone line type ports or any of a variety of types of ports. As an operative example, the first port **82***a* can be configured to connect the connector board **80** to the temperature collection module **110** or directly to the central computer system **120**, while the second data port **82***b* can be configured to connect to the sensor assembly **10**, to collect temperature data from the plurality of sensors **14**. Additionally, the first data port **82***a* can be configured to connect the connector board to another connector board associated with another rack, thereby enabling multiple connector boards to be connected to a central computer system in a daisy chain fashion, like that shown in FIG. **6**.

A third input port **82***c* can also be provided to connect to a second sensor assembly (not shown) that can be associated with the rack. This sort of configuration is suggested by FIGS. **4** and **5**. As shown in FIG. **4**, the connector wire **16** from the front sensor assembly is connected to the connector board. Likewise, a connector wire from the rear sensor assembly also extends to a connection point with the connector board. Consequently, a third or more additional input ports will be needed to provide connectivity to the interconnecting lines **84** that interconnect the rack to the central computer and/or other racks.

In the connection scheme shown in FIG. **7**, the data leads and ground leads of the temperature sensors **14** are coupled in parallel to the first and second RJ11 ports **82***a*, **82***b* via the data line **86** and ground line **88**. These lines correspond to the flat conductor data line **24***a* and connector wire data line **16***a*, and the flat conductor ground line **24***b* and connector wire ground line **16***b*, respectively. The memory device is also connected to the data and ground lines at the head of the line of sensors. As a result, the plurality of sensors are connected in parallel to the temperature collection module (**120** in FIG. **6**) via the data line and the ground line. This concept is advantageous with respect to conventional methodology in that conventional methodology suggests a point-to-point connection from each sensor to a central data collection system. By employing the above-described concepts, multiple temperature sensors are coupled to a central data collection system (the temperature collection module) via the data line and the ground line. This is substantially more efficient than conventional methodology, and allows the temperature sensors to be installed during production and connected together in the field.

Referring back to FIG. **6**, the temperature collection module **120** is coupled to the central computer system **110** and at least one of the connector boards **140**(*a* . . . *n*). The temperature collection module can be included in the central computer system or can be configured in a device separate from the central computer system. In accordance with an embodiment, the temperature collection module collects temperature data from each plurality of temperature sensors **130**(*a* . . . *n*). The temperature collection module includes connector board interface electronics, temperature collection logic, and central computer system interface electronics. The connector board interface electronics are coupled to the temperature collection logic wherein the temperature collection logic is further coupled to the central computer system interface electronics. The temperature collection logic is further coupled to a temperature data table that maintains the readings of the sensors. One of ordinary skill in the art will readily recognize the elements and features of the temperature collection module can be configured in a variety of ways.

The temperature collection logic periodically queries the data table which contains the temperature readings of each plurality of the sensors. In order to access individual sensors it is necessary to know the address identifier of each of the individual sensors along with the physical location. This issue is complicated by the fact that the individual sensors are factory programmed with unique address information that is not re-programmable. However, this problem is solved by the memory device associated with each sensor assembly. The memory device stores the identifier of each sensor on the sensor assembly. The memory devices are programmed during the assembly of the sensor assembly. Data is stored in the memory device that indicates a unique identifying number for the sensor assembly itself. Also stored in the memory are the unique 1-wire addresses of each sensor device installed on the sensor assembly. These addresses are stored in a table in the same order as the physical order of the devices on the sensor assembly. It would also be possible to associate the sensor assembly with a particular rack if it was installed on this rack at the factory. Alternatively the rack information could be programmed in the field using a simple tool designed for this purpose. Using this information, it is possible for a temperature collection module to automatically configure its data collection logic when a sensor assembly is added to its 1-wire network.

Additionally, in another alternative embodiment, the temperature collection module can be implemented as a "row manager" device. Accordingly, the module can be capable of communication with an Ethernet network connection while communicating with the plurality of sensors.

In accordance with one method of collecting temperature data, a temperature data acquisition [illegible]

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the periodic querying of each of the sensors in the data center, providing a "start conversion" command whereby the process of taking temperature readings from the individual sensors is initiated. This process takes approximately ¾ to one second per sensor when using the parasitically powered sensor devices described above. If faster results are desired, sensors are available with a separate power supply pin for a much faster response. This would be one configuration in which three conductors in the sensor assembly and in the connecting wire would be needed.

Once the temperature is measured from each sensor, temperature collection logic stores the temperature readings in a data table and generates a temperature profile of the data center based on the temperature readings. Separate temperature tables can be generated based on the varying locations of sensors. For example, based on the location of the sensors temperature profiles can be generated for the front of the rack, the back of the rack, etc.

In varying embodiments, the data center could employ more than one temperature collection module. In this case, the data table in each module will only contain part of the temperature profile of the data center. Accordingly, the central computer can assemble partial profiles of the data center. These partial profiles can subsequently be combined to form a global temperature profile of the data center.

The method of obtaining temperature data from an installation of sensors is generally as follows. A first step includes periodically querying of each of the sensors in the data center. A second step includes providing an initiation command. A third step includes reading the measured temperature of each of the sensors. A final step involves generating a temperature profile of the data center based on the temperature readings. The temperature profile can include a variety of profiles based on the locations of the sensors, and can be presented in a 3-dimensional matrix view format. The above-described method may be implemented, for example, by operating a computer system to execute a sequence of machine-readable instructions. The instructions may reside in various types of computer readable media.

Although the application and use of the sensor assembly is disclosed in the context of a data center, one of ordinary skill in the art will readily recognize that the functionality of the varying embodiments of the sensor assembly can be utilized in a variety of different facilities. Specifically, this type of sensor assembly is by no means limited to data center applications, and is not limited to temperature sensing.

It is to be understood that the above-referenced arrangements are illustrative of the application of the principles of the present invention. It will be apparent to those of ordinary skill in the art that numerous modifications can be made without departing from the principles and concepts of the invention as set forth in the claims.

What is claimed is:

1. A modular sensor assembly for sensing a condition at a computer rack, comprising:

a) an elongate flexible body, configured to attach to a computer rack;

b) a plurality of addressable sensors, disposed along the body and interconnected to a common connector wire; and

c) a connector wire lead, configured to interconnect the connector wire to a central system configured to receive and interpret data from the plurality of sensors relating to conditions associated with the computer rack.

2. A sensor assembly in accordance with claim **1**, further comprising a connector board, associated with the computer rack, configured to modularly interconnect the connector wire lead to a communication wire in communication with the central system.

3. A sensor assembly in accordance with claim **2**, further comprising a communication wire interconnected between the connector board and a connector board of an additional computer rack having a modular sensor assembly, so as to interconnect a network of modular sensor assemblies to the central system.

4. A sensor assembly in accordance with claim **1**, wherein the elongate body comprises a substantially rigid outer covering, containing the connector wire and addressable sensors, having connectors attached thereto for connecting the outer covering to the computer rack.

5. A sensor assembly in accordance with claim **4**, wherein the outer covering is configured as a decorative trim strip for the computer rack.

6. A sensor assembly in accordance with claim **4**, wherein the outer covering is configured to attach to a door of the computer rack.

7. A sensor assembly in accordance with claim **1**, wherein the elongate body comprises a plurality of body segments interconnected by an interconnecting wire.

8. A sensor assembly in accordance with claim **1**, further comprising an adhesive, disposed on the elongate body, configured to allow the sensor assembly to be adhesively attached to the computer rack.

9. A sensor assembly in accordance with claim **1**, wherein the connector wire and the connector wire lead comprise two electrical conductors, including a data wire and a ground wire, and wherein the plurality of sensors are attached in parallel to the ground wire and the data wire, and configured to draw power from the data wire.

10. A sensor assembly in accordance with claim **1**, wherein the sensors are selected from the group consisting of temperature sensors, humidity sensors, fluid pressure sensors, fluid velocity sensors, smoke sensors, occupancy sensors, a computer rack door condition sensor, and light sensors.

11. A sensor system, comprising:

a) a computer rack;

b) a modular sensor assembly, having a flexible elongate body, attached to the computer rack;

c) a plurality of addressable sensors, disposed along the elongate body of the modular sensor assembly, and interconnected in parallel to a common connector wire, configured to independently measure an environmental condition in the immediate vicinity of the sensor;

d) a connector wire lead, interconnected to the common connector wire; and

e) a central system, interconnected to the connector wire lead, configured to receive and interpret data from the plurality of addressable sensors.

12. A system in accordance with claim **11**, wherein the computer rack includes means for receiving the modular sensor assembly.

13. A system in accordance with claim **12**, wherein the means for receiving the modular sensor assembly is selected from the group consisting of a trim strip, associated with the computer rack and configured to receive the modular sensor assembly, and a plurality of apertures, disposed on members of the computer rack, configured to receive connectors associated with the modular sensor assembly.

14. A system in accordance with claim **11**, wherein the modular sensor assembly is disposed on a front of the computer rack.

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15. A system in accordance with claim 14, wherein the modular sensor assembly is disposed on a front door of the computer rack.

16. A system in accordance with claim 11, wherein the modular sensor assembly is disposed on a rear of the computer rack.

17. A system in accordance with claim 11, wherein the modular sensor assembly is disposed so as to place a sensor above the computer rack.

18. A system in accordance with claim 11, wherein the modular sensor assembly comprises a plurality of flexible elongate body segments interconnected by an interconnecting wire.

19. A system in accordance with claim 11, further comprising a connector board, associated with the computer rack, configured to modularly interconnect the connector wire lead to a communication wire in communication with the central system.

20. A system in accordance with claim 19, further comprising a second modular sensor assembly, connected to the computer rack, and interconnected to the connector board.

21. A system in accordance with claim 19, further comprising a second computer rack having a second connector board and a modular sensor assembly connected to the second computer rack and the second connector board, and a communications wire connected between the connector board and the second connector board.

22. A system in accordance with claim 11, wherein the plurality of sensor devices are selected from the group consisting of temperature sensors, humidity sensors, fluid pressure sensors, fluid velocity sensors, smoke sensors, occupancy sensors, computer rack door condition sensors, and light sensors.

23. A system in accordance with claim 11, wherein the common connector wire comprises two conductors, including a data wire and a ground wire, the sensors being interconnected to the data wire and ground wire in parallel.

24. A system in accordance with claim 23, wherein the sensors are configured to draw power from the data wire.

25. A system in accordance with claim 11, wherein the modular sensor assembly comprises:

a) a pair of substantially flat flexible conductors, disposed on a substrate, a first of the conductors a ground wire, and a second of the conductors being a data wire; and

b) a ground lead of each sensor device being connected to the first conductor, and a data lead of each sensor device being connected to the second conductor.

26. A system in accordance with claim 11, wherein the central system comprises an environmental monitor, configured to selectively collect data from each of the addressable sensors, and to determine spatially-correlated environmental conditions related to the computer rack.

27. A system in accordance with claim 11, further comprising a modular sensor assembly disposed on a front of the computer rack, and a modular sensor assembly disposed on a rear of the computer rack, the front sensor assembly being configured to detect a temperature of cooling air supplied to the front of the rack, and the rear sensor assembly being configured to detect a temperature of return air exhausted from the rear of the rack.

28. A computer rack system, comprising:

a) a generally upright rack body, configured to support heat-generating electronic devices, and to allow cooling air to flow therethrough;

b) a modular sensor assembly, attached to the rack body, comprising an elongate flexible sensor body having a plurality of addressable sensors connected in parallel to a common connector wire, each sensor being configured to generate a digital signal representative of an environmental condition; and

c) a connector board, associated with the rack body, interconnected to the connector wire and to a central computer system configured to receive data from the plurality of sensors and to monitor environmental conditions associated with the rack.

* * * * *

EXHIBIT F

IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF TEXAS
MARSHALL DIVISION

Valtrus Innovations Ltd.	§	
	§	
Plaintiff,	§	
v.	§	**CIVIL ACTION NO. 2:24-cv-00259**
	§	
CyrusOne, LLC	§	**JURY TRIAL DEMANDED**
	§	
Defendant.	§	
	§	
	§	

COMPLAINT FOR PATENT INFRINGEMENT AND JURY DEMAND

Plaintiff Valtrus Innovations Limited ("Plaintiff" or "Valtrus"), by and through its undersigned counsel, brings this complaint for patent infringement and damages against Defendant CyrusOne, LLC ("CyrusOne" or "Defendant") and would respectfully show the Court as follows:

PARTIES

1. Valtrus is the successor-in-interest to a substantial patent portfolio created by Hewlett Packard Enterprise and its predecessor, subsidiary, and affiliate companies (collectively, "HPE"). Valtrus is an Irish entity duly organized and existing under the laws of the Republic of Ireland. The address of the registered office of Valtrus is: The Glasshouses GH2, 92 Georges Street Lower, Dun Laoghaire, Dublin A96 VR66, Ireland. HPE's worldwide corporate headquarters is located in Houston, Texas. One of HPE's primary U.S. facilities is located in Plano, Texas.

2. On information and belief, CyrusOne is a limited liability company organized and existing under the laws of the State of Delaware, with a principal place of business at 2850 North Harwood Street, Suite 2200, Dallas, TX 75201. CyrusOne has a regular and established place of business at three data centers located in this District: DFW1, 1649 West Frankford Rd., Carrollton,

TX 75007; DFW2, 2501 S. State Hwy 121, Business Suite 500 (Bldg #5), Lewisville, TX 75067; and DFW3, 2300 Chelsea Blvd, Allen, TX 75013 (collectively referred to as "DFW Data Centers"). On information and belief, CyrusOne may be served with process through its registered agent at Corporation Service Company, 211 East 7th St., Suite 620, Austin, TX 78701.

PATENTS IN SUIT

3. Valtrus is the assignee of and owns all right and title to U.S. Patent Nos. 6,718,277 (the "'277 Patent"); 6,854,287 (the "'287 Patent"); 6,862,179 (the "'179 Patent"); 7,031,870 (the "'870 Patent"); 7,339,490 (the "'490 Patent"); 9,310,855 (the "'855 Patent"); and 7,939,967 (the "'967 Patent") (collectively, "the Asserted Patents").

4. The Asserted Patents were developed by inventors working for HPE. HPE developed numerous innovative and diverse technologies, including groundbreaking inventions pertaining to data center cooling, analytics for monitoring conditions in data centers, and structural organization of data centers.

5. The '277 Patent, entitled "Atmospheric control within a building," was duly and lawfully issued on April 6, 2004. A true and correct copy of the '277 Patent is attached hereto as Exhibit 1.

6. The '277 Patent was in full force and effect since its issuance. Valtrus owns by assignment the entire right and title in and to the '277 Patent, including the right to seek damages, including past damages, for any infringement thereof.

7. The '287 Patent, entitled "Cooling system," was duly and lawfully issued on February 15, 2005. A true and correct copy of the '287 Patent is attached hereto as Exhibit 2.

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8. The ’287 Patent was in full force and effect since its issuance. Valtrus owns by assignment the entire right and title in and to the ’287 Patent, including the right to seek damages, including past damages, for any infringement thereof.

9. The ’179 Patent, entitled “Partition for varying the supply of cooling fluid,” was duly and lawfully issued on March 1, 2005. A true and correct copy of the ’179 Patent is attached hereto as Exhibit 3.

10. The ’179 Patent was in full force and effect since its issuance. Valtrus owns by assignment the entire right and title in and to the ’179 Patent, including the right to seek damages, including past damages, for any infringement thereof.

11. The ’870 Patent, entitled “Data center evaluation using an air re-circulation index,” was duly and lawfully issued on April 18, 2006. A true and correct copy of the ’870 Patent is attached hereto as Exhibit 4.

12. The ’870 Patent has been in full force and effect since its issuance. Valtrus owns by assignment the entire right and title in and to the ’870 Patent, including the right to seek damages, including past damages, for any infringement thereof.

13. The ’490 Patent, entitled “Modular sensor assembly,” was duly and lawfully issued on March 4, 2008. A true and correct copy of the ’490 Patent is attached hereto as Exhibit 5.

14. The ’490 Patent has been in full force and effect since its issuance. Valtrus owns by assignment the entire right and title in and to the ’490 Patent, including the right to seek damages for any infringement thereof.

15. The ’855 Patent, entitled “Flexible data center and methods for deployment,” was duly and lawfully issued on April 12, 2016. A true and correct copy of the ’855 Patent is attached hereto as Exhibit 6.

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16. The ’855 Patent has been in full force and effect since its issuance. Valtrus owns by assignment the entire right and title in and to the ’855 Patent, including the right to seek damages, including past damages, for any infringement thereof.

17. The ’967 Patent, entitled “Multiple Power Supply Control,” was duly and lawfully issued on May 10, 2011. A true and correct copy of the ’967 Patent is attached hereto as Exhibit 7.

18. The ’967 Patent has been in full force and effect since its issuance. Valtrus owns by assignment the entire right and title in and to the ’967 Patent, including the right to seek damages, including past damages, for any infringement thereof.

19. CyrusOne has been on notice of the Asserted Patents and its infringement since at least April 1, 2024. Valtrus sent CyrusOne a letter on March 29, 2024 regarding a Notice of Infringement of Valtrus Innovation Ltd.’s Patents (“Notice Letter”). The Notice Letter was delivered to CyrusOne on April 1, 2024. The Notice Letter was addressed to CyrusOne’s Executive Vice President, General Counsel & Secretary Robert M. Jackson, and provided the specific factual basis for Valtrus’ allegations of infringement. The Notice Letter also proposed a meeting to discuss a potential license or other arrangement between Valtrus and CyrusOne.

20. CyrusOne, through Mr. Jackson, responded to the Notice Letter on April 11, 2024 declining Valtrus’ request for a meeting.

JURISDICTION AND VENUE

21. Valtrus incorporates by reference paragraphs 1-20 herein.

22. This civil action arises under the patent laws of the United States, 35 U.S.C. § 1 *et seq.*, including without limitation 35 U.S.C. §§ 271, 281, 283, 284, and 285. This is a patent infringement lawsuit over which this Court has subject matter jurisdiction under, *inter alia*, 28 U.S.C. §§ 1331, 1332, and 1338(a).

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23. This District has general and specific personal jurisdiction over CyrusOne because, directly or through intermediaries, CyrusOne has committed acts within this District giving rise to this action; is present in and transacts and conducts business, directly, and/or indirectly, in this District and the State of Texas; and transacts and conduct business with residents of this District and the State of Texas.

24. Valtrus's causes of action arise, at least in part, from CyrusOne's contacts with and activities in and/or directed at this District and the State of Texas.

25. CyrusOne has infringed the Asserted Patents within this District and the State of Texas by making, using, selling, offering for sale, and/or importing in or into this District and elsewhere in the State of Texas, products and services covered by claims in the Asserted Patents, including without limitation products that, when made or used, practice the claimed methods of the Asserted Patents. CyrusOne, directly and through intermediaries, makes, uses, sells, offers for sale, imports, ships, distributes, advertises, promotes, and/or otherwise commercializes such infringing products and services in or into this District and the State of Texas. CyrusOne regularly conducts and solicits business in, engages in other persistent courses of conduct in, and/or derives substantial revenue from goods and services provided to residents of this District and the State of Texas.

26. This Court has personal jurisdiction over CyrusOne pursuant to TEX. CIV. PRAC. & REM. CODE § 17.041 *et seq.*

27. Venue is proper in this District under 28 U.S.C. §§ 1391(b)-(c) and 1400(b).

28. CyrusOne is doing business, either directly or through respective agents, on an ongoing basis in this Judicial District and elsewhere in the United States and has committed acts of infringement in this district. CyrusOne has a regular and established place of business in this

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Judicial District, including at its DFW Data Centers. On information and belief, CyrusOne makes, uses, sells, offers to sell, and/or imports infringing products into and/or within this District, including at its DFW Data Centers. CyrusOne maintains a permanent and/or continuing presence within this District at its DFW Data Centers, and has the requisite minimum contacts with this District such that this venue is a fair and reasonable one. Upon information and belief, CyrusOne has transacted and, at the time of the filing of the Complaint, is continuing to transact business within this District.

FIRST CLAIM

(Infringement of the '277 Patent)

29. Valtrus re-alleges and incorporates herein by reference paragraphs 1-28 of its Complaint.

30. The '277 Patent is generally directed to atmospheric control within a building.

31. CyrusOne has, under 35 U.S.C. § 271(a), directly infringed, literally and/or under the doctrine of equivalents, one or more claims, including without limitation at least claim 1, of the '277 Patent, by making, using, selling, offering for sale, and/or importing systems in its data centers for cooling, or otherwise controlling atmospheric conditions within, the data centers. For example, on information and belief, and before the expiration of the '277 Patent, CyrusOne operated cooling systems in its data centers in a manner that infringed the '277 Patent. An exemplary claim chart demonstrating one way in which CyrusOne infringed claim 1 of the '277 Patent is attached as Exhibit 8.

32. As a result of CyrusOne's infringing activity, Valtrus has been damaged.

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SECOND CLAIM

(Infringement of the '287 Patent)

33. Valtrus re-alleges and incorporates herein by reference paragraphs 1-32 of its Complaint.

34. The '287 Patent is generally directed to a system and method for cooling a room configured to house a plurality of computer systems.

35. CyrusOne has, under 35 U.S.C. § 271(a), directly infringed, literally and/or under the doctrine of equivalents, one or more claims, including without limitation at least claim 1 of the '287 Patent, by making, using, selling, offering for sale, and/or importing systems in its datacenters for cooling the datacenters. For example, on information and belief, and before the expiration of the '287 Patent, CyrusOne operated cooling systems in its data centers in a manner that infringed the '287 Patent. An exemplary claim chart demonstrating one way in which CyrusOne infringed claim 1 of the '287 Patent is attached as Exhibit 9.

36. As a result of CyrusOne's infringing activity, Valtrus has been damaged.

THIRD CLAIM

(Infringement of the '179 Patent)

37. Valtrus re-alleges and incorporates herein by reference paragraphs 1-36 of its Complaint.

38. The '179 Patent is generally directed to a partition for varying the supply of cooling fluid in a data center.

39. CyrusOne has, under 35 U.S.C. § 271(a), directly infringed, literally and/or under the doctrine of equivalents, one or more claims, including without limitation at least claim 1 of the '179 Patent, by making, using, selling, offering for sale, and/or importing cooling systems in its

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data centers, including a partition for varying the supply of cooling fluid. For example, on information and belief, and before the expiration of the '179 Patent, CyrusOne operated cooling systems in its data centers in a manner that infringes the '179 Patent. An exemplary claim chart demonstrating one way in which CyrusOne infringes claim 1 of the '179 Patent is attached as Exhibit 10.

40. As a result of CyrusOne's infringing activity, Valtrus has been damaged.

FOURTH CLAIM

(Infringement of the '870 Patent)

41. Valtrus re-alleges and incorporates herein by reference paragraphs 1-40 of its Complaint.

42. The '870 Patent is generally directed to a system and method for evaluating one or more components in a data center.

43. CyrusOne has been on notice of the '870 Patent and a specific factual basis for its infringement of the '870 Patent since at least the date of Valtrus' Notice Letter. On information and belief, CyrusOne did not take any action to stop its infringement.

44. CyrusOne has, under 35 U.S.C. § 271(a), directly infringed, literally and/or under the doctrine of equivalents, one or more claims, including without limitation at least claim 1 of the '870 Patent, by making, using, selling, offering for sale, and/or importing cooling systems in its data centers. For example, on information and belief, CyrusOne operates cooling systems in its data centers in a manner that infringes the '870 Patent. An exemplary claim chart demonstrating one way in which CyrusOne infringes claim 1 of the '870 Patent is attached as Exhibit 11.

45. To the extent CyrusOne has failed to take any action to stop its infringement after being placed on notice of the above, such infringement has been willful.

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46. As a result of CyrusOne's infringing activity, Valtrus has been damaged.

FIFTH CLAIM

(Infringement of the '490 Patent)

47. Valtrus re-alleges and incorporates herein by reference paragraphs 1-46 of its Complaint.

48. The '490 Patent is generally directed to a modular sensor assembly for sensing conditions at a computer rack, such as environmental conditions.

49. CyrusOne has been on notice of the '490 Patent and a specific factual basis for its infringement of the '490 Patent since at least the date of Valtrus' Notice Letter. On information and belief, CyrusOne did not take any action to stop its infringement.

50. CyrusOne has, under 35 U.S.C. § 271(a), directly infringed, literally and/or under the doctrine of equivalents, one or more claims, including without limitation at least claim 1 of the '490 Patent, by making, using, selling, offering for sale, and/or importing modular sensor assemblies for sensing conditions such as temperature at a computer rack in its data centers. For example, on information and belief, CyrusOne's data centers operate using modular sensor assemblies that infringe the '490 Patent. An exemplary claim chart demonstrating one way in which CyrusOne infringes claim 1 of the '490 Patent is attached as Exhibit 12.

51. To the extent CyrusOne has failed to take any action to stop its infringement after being placed on notice of the above, such infringement has been willful.

52. As a result of CyrusOne's infringing activity, Valtrus has been damaged.

SIXTH CLAIM

(Infringement of the '855 Patent)

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53. Valtrus re-alleges and incorporates herein by reference paragraphs 1-52 of its Complaint.

54. The ’855 patent is generally directed to a flexible data center and methods for deployment of flexible data centers.

55. CyrusOne has been on notice of the ’855 Patent and a specific factual basis for its infringement of the ’855 Patent since at least the date of Valtrus’ Notice Letter. On information and belief, CyrusOne did not take any action to stop its infringement.

56. CyrusOne has, under 35 U.S.C. § 271(a), directly infringed, literally and/or under the doctrine of equivalents, one or more claims, including without limitation at least claim 8 of the ’855 Patent, by making, using, selling and/or offering for sale flexible data centers. For example, on information and belief, CyrusOne’s DFW1 Data Center located in this District (as well as other data centers across the United States) infringes the ’855 Patent. An exemplary claim chart demonstrating one way in which CyrusOne infringes claim 8 of the ’855 Patent is attached as Exhibit 13.

57. To the extent CyrusOne has failed to take any action to stop its infringement after being placed on notice of the above, such infringement has been willful.

58. As a result of CyrusOne’s infringing activity, Valtrus has been damaged.

SEVENTH CLAIM

(Infringement of the ’967 Patent)

59. Valtrus re-alleges and incorporates herein by reference paragraphs 1-58 of its Complaint.

60. The ’967 patent is generally directed to multiple power supply control in data centers.

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61. CyrusOne has been on notice of the '967 Patent and a specific factual basis for its infringement of the '967 Patent since at least the date of Valtrus' Notice Letter. On information and belief, CyrusOne did not take any action to stop its infringement.

62. CyrusOne has, under 35 U.S.C. § 271(a), directly infringed, literally and/or under the doctrine of equivalents, one or more claims, including without limitation at least claim 1 of the '967 Patent, by making, using, selling and/or offering for sale data centers using multiple power supply control. For example, on information and belief, CyrusOne's redundant power systems in its U.S. data centers infringe the '967 Patent. An exemplary claim chart demonstrating one way in which CyrusOne infringes claim 1 of the '967 Patent is attached as Exhibit 14.

63. To the extent CyrusOne has failed to take any action to stop its infringement after being placed on notice of the above, such infringement has been willful.

64. As a result of CyrusOne's infringing activity, Valtrus has been damaged.

PRAYER FOR RELIEF

WHEREFORE, Valtrus prays for judgment against CyrusOne as follows:

A. That CyrusOne has infringed each of the Asserted Patents, and unless enjoined, will continue to infringe one or more of the applicable Asserted Patents;

B. That CyrusOne's infringement of one or more of the applicable Asserted Patents has been willful;

C. That CyrusOne pay Valtrus damages adequate to compensate Valtrus for CyrusOne's past infringement of each of the Asserted Patents, and present and future infringement of the applicable Asserted Patents, together with interest and costs under 35 U.S.C. § 284;

D. That CyrusOne pay prejudgment and post-judgment interest on the damages assessed;

E. That CyrusOne pay Valtrus enhanced damages pursuant to 35 U.S.C. § 284;

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F. That CyrusOne be enjoined from infringing the ’870, ’490, ’855, and ’967 Patents, or if its infringement is not enjoined, that CyrusOne be ordered to pay ongoing royalties to Valtrus for any post-judgment infringement of the ’870, ’490, ’855, and ’967 Patents;

G. That this is an exceptional case under 35 U.S.C. § 285; and that CyrusOne pay Valtrus’s attorneys’ fees and costs in this action; and

H. That Valtrus be awarded such other and further relief, including equitable relief, as this Court deems just and proper.

DEMAND FOR JURY TRIAL

Pursuant to Federal Rule of Civil Procedure 38(b), Valtrus hereby demands a trial by jury on all issues triable to a jury.

April 18, 2024

Respectfully submitted,

/s/ Eric H. Findlay

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Attorneys for Plaintiff
Valtrus Innovations Limited

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Exhibit 8

U.S. Patent No. 6,718,277 – Infringement Claim Chart

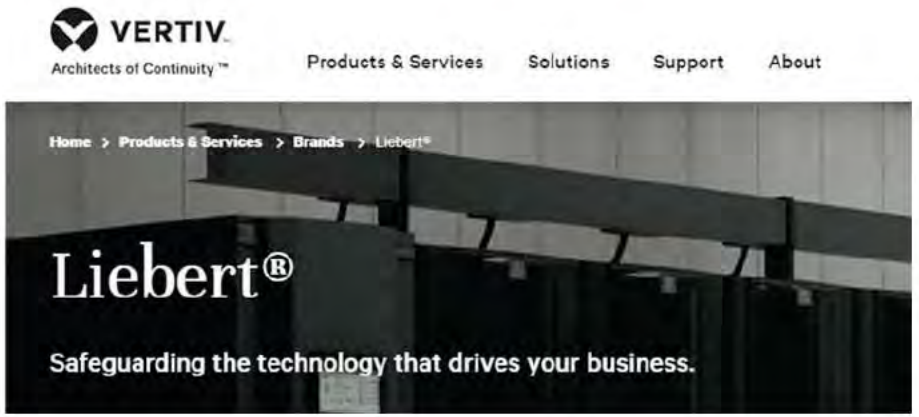
Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1pre] A method of controlling atmospheric conditions within a building, said method comprising the steps of:	CyrusOne's data centers use a method of controlling atmospheric conditions within a building. CyrusOne uses Vertiv and Liebert cooling in its U.S. data centers to control atmospheric conditions. Liebert's cooling units are controlled, for example, by Liebert's iCOM and/or iCOM-S Intelligent Communication and Monitoring System, which uses a method for evaluating one or more components in a data center.  https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

Cooling

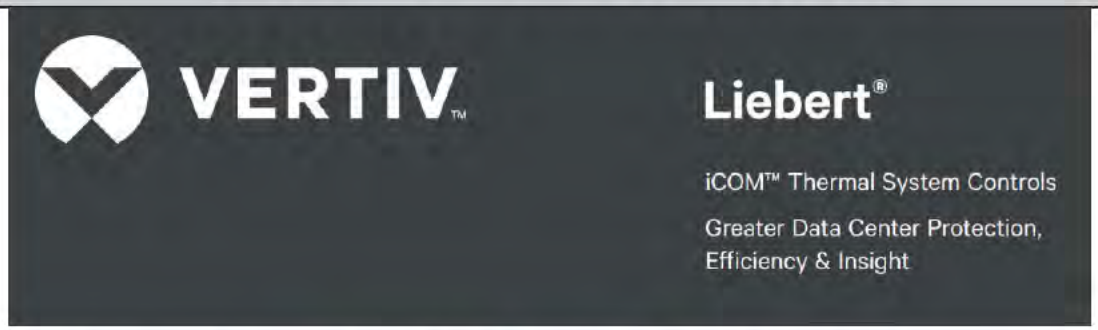
- N+1 Cooling
- Redundant DX and Glycol Chillers
- Redundant raised floor CRAC units
- 12in Raised floor

https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.



https://www.vertiv.com/en-us/products/brands/liebert/

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.vertiv.com/49d637/globalassets/shared/liebert-icom-thermal-system-controls-brochure.pdf ("iCOM Brochure").

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Claim 1	Exemplary Evidence of Infringement by CyrusOne

At the cooling unit level, the Liebert iCOM unit control provides the highest protection available and optimal performance.

- Monitors 380 unit and component points to eliminate single points of failure
- Self-healing features avoid passing unsafe operating thresholds
- Highly intuitive, full-color, touch screen simplifies operations to save time and reduce human error
- Multiple, automated unit protection routines, including lead/lag, cascade, rapid restart, refrigerant protection and valve calibration



At the supervisory level, the Liebert iCOM-S system control offers a revolutionary way to harmonize and optimize thermal system performance to optimize capacity across the data center, gain quick access to actionable data, and automate system diagnostics and trending.

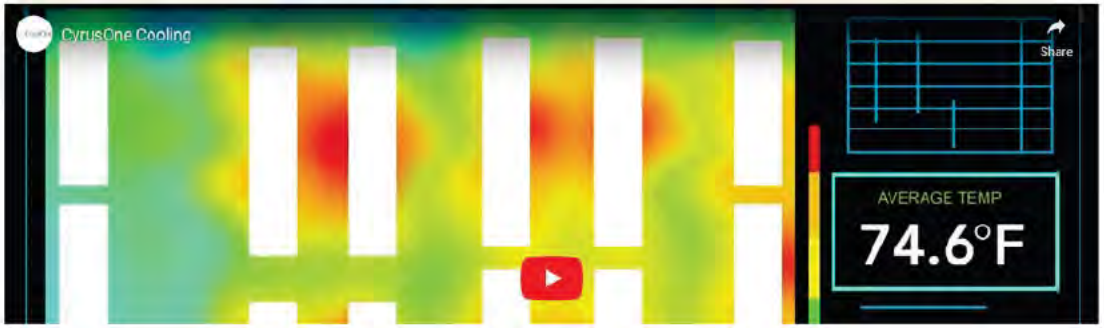
- Advanced monitoring and at-a-glance reporting on performance metrics and trends for efficiency, capacity and adverse events
- Up to 50% system efficiency gains
- 30% lower deployment costs
- Teamwork modes that prevent conflict between units and allow them to adapt to changes in facility and IT demand to improve efficiency and availability and reduce system wear and tear – saving more than $10,000 per unit per year in energy costs
- Simple and easy to deploy — auto-configuration to detect and configure up to 4,800 sensors, eliminating the need for custom integration to building management systems and cutting sensor deployment times in half



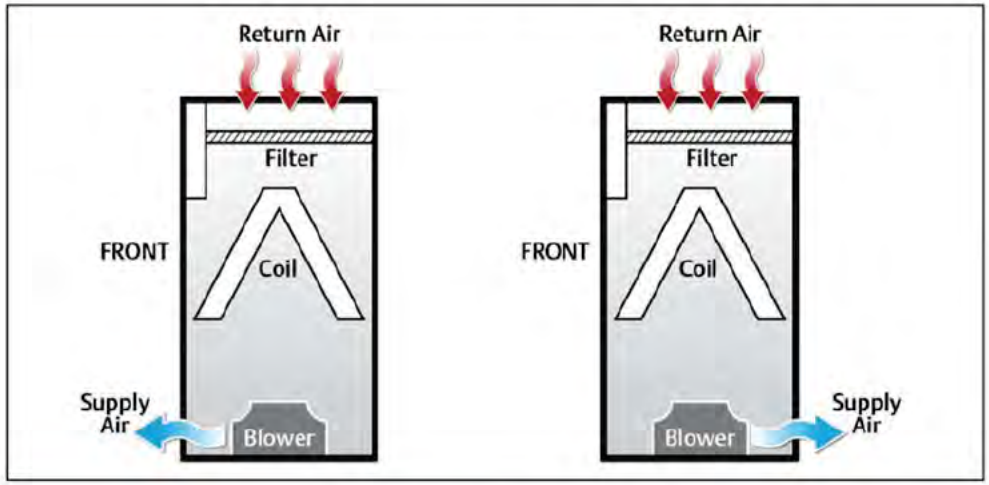
Liebert iCOM unit control and Liebert iCOM-S system control are available for new Vertiv™ data center cooling units or as retrofits.

iCOM Brochure at p. 3.

CyrusOne also uses CyrusOne cooling software to measure, monitor, and manage atmospheric conditions in its data centers.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	CyrusOne's data center cooling systems are some of the most advanced in the world employing proactive and reactive methods to keep customer's data halls running at the most optimal temperatures.  https://www.cyrusone.com/data-center-solutions/colocation
[1a] supplying a conditioned fluid inside said building;	CyrusOne supplies a conditioned fluid inside said building. For example, CyrusOne uses CRAC units inside its data centers to supply conditioned fluid. CyrusOne uses Liebert to control atmospheric conditions in the data center with its CRAC units. CyrusOne supplies refrigerant (conditioned fluid) through the coil of its Liebert CRAC units. The Liebert CRAC unit receives the "return air" from the room and delivers cool conditioned "supply air" to the room (supplying conditioned fluid), by transferring heat from the air to the cooling fluid within the coil.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.vertiv.com/4afe7d/globalassets/products/thermal-management/room-cooling/liebert-dse-80-165kw-23-43-tons-downflow-system-design-manual.pdf, at p. 6. Regardless of which type of CRAC units or which method of controlling atmospheric conditions are used (Liebert, CyrusOne, or others), CyrusOne supplies a conditioned fluid inside each of its data centers.
[1b] sensing at least one atmospheric parameter in a plurality of locations inside said building;	CyrusOne senses at least one atmospheric parameter in a plurality of locations inside said building. For example, CyrusOne uses Liebert iCOM. Liebert iCOM senses temperatures and humidity at locations throughout the data center.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	User Temperature Setpoint Options **2nd Temperature Setpoint** Alternate setpoint activated by customer input (remote alarm device). When customer input connection is 2nd Setpoint, this value becomes the active temperature setpoint. **BMS Backup Temp Setpoint** Selects a temperature setpoint that activates in the event of a BMS timeout. The BMS timer must be configured for this setpoint to activate. See Setting BMS Backup Setpoints on page 117. **Optimized Aisle Enabled** Read-only. Indicates that iCOM™ is configured for optimized-aisle operation. See Teamwork Mode 3—Optimized Aisle Operation on page 102. **Temperature Control Sensor** Selects sensor that controls cooling. Values are: • Supply Sensor: Temperature control is based on maintaining the temperature of the discharge air from the cooling unit. See Supply Sensors on page 158. • Remote Sensor: Temperature control is based on the temperature reading(s) from wired remote sensor(s). See Wired Remote Sensors on page 156. • Return Sensor: Temperature control is based on maintaining the temperature of the air returning to the cooling unit.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	User Humidity Setpoint Options **Dew Point Setpoint** Desired dew point (based on actual return air temperature and humidity) by adding moisture to or removing moisture from the air. **Humidity Control Sensor** Selects sensor used when calculating relative humidity. **Humidity Control Type** Control when staging humidification operations. Valid values: • Relative: Percent of humidification/dehumidification is determined by the difference between the humidity-sensor reading and the humidity setpoint. • Compensated: Percent of humidification/dehumidification is determined by considering the actual deviation from the temperature setpoint and adjusts the humidity setpoint accordingly. The recalculated humidity setpoint displays on the screen. • Predictive: Percent of humidification/dehumidification is determined by considering the actual deviation from the temperature setpoint and adjusts the humidity sensor reading accordingly. The adjusted humidity sensor reading displays on the screen. • Dew point: Percent of humidification/dehumidification is determined by the difference between the dew point calculated from the humidity sensor reading and the dew point setpoint. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf ("iCOM Manual") at p. 15-16. CyrusOne also uses CyrusOne Cooling to sense temperatures based on real sensor readings at various locations inside the data center.

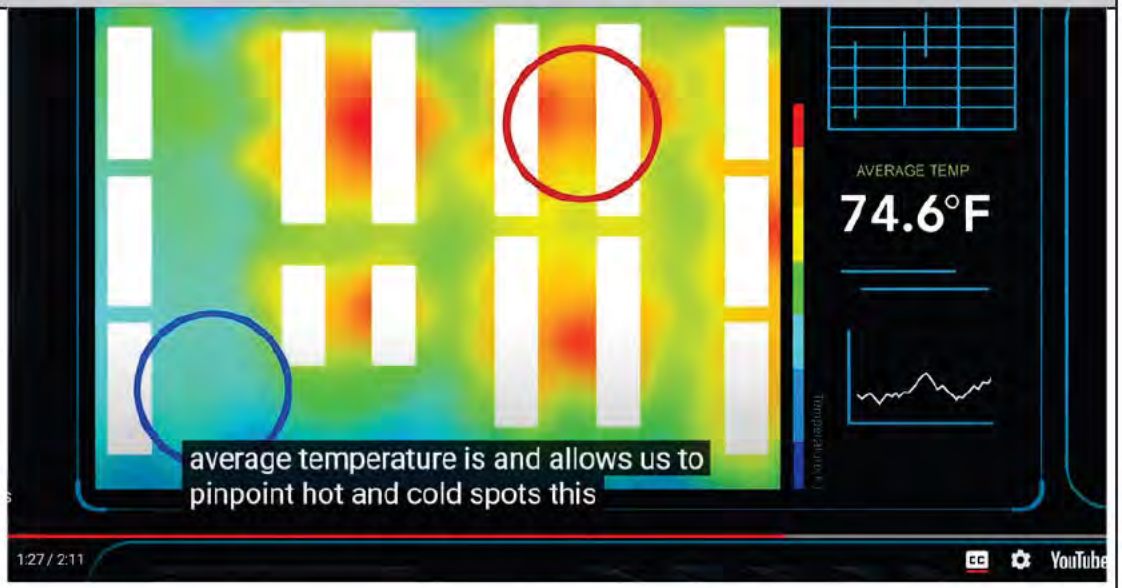
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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.youtube.com/watch?v=yFMS-88wXn8, at 1:16.

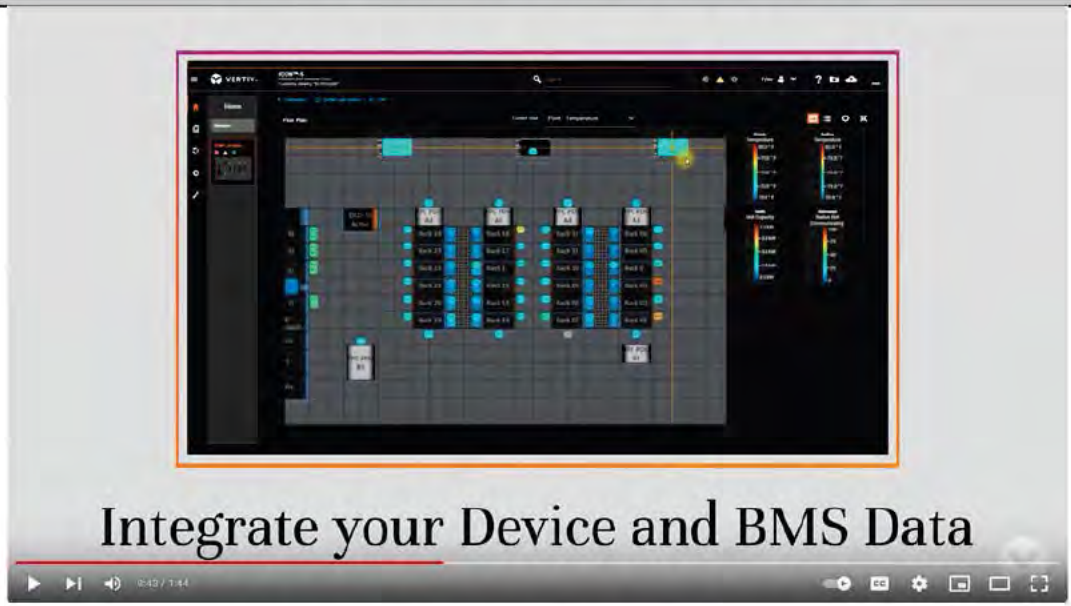
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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.youtube.com/watch?v=yFMS-88wXn8, at 1:21.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.cyrusone.com/data-center-solutions/colocation , at 1:27;
[1c] generating an empirical atmospheric map from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical atmospheric map;	CyrusOne an empirical atmospheric map from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical atmospheric map. For example, CyrusOne uses Liebert iCOM. Liebert iCOM generates an empirical atmospheric map from the results of sensing temperature at individual racks. Liebert iCOM uses software for processing temperature inputs from the sensing step and produces output in the form of a data center temperature map.

Claim 1	Exemplary Evidence of Infringement by CyrusOne



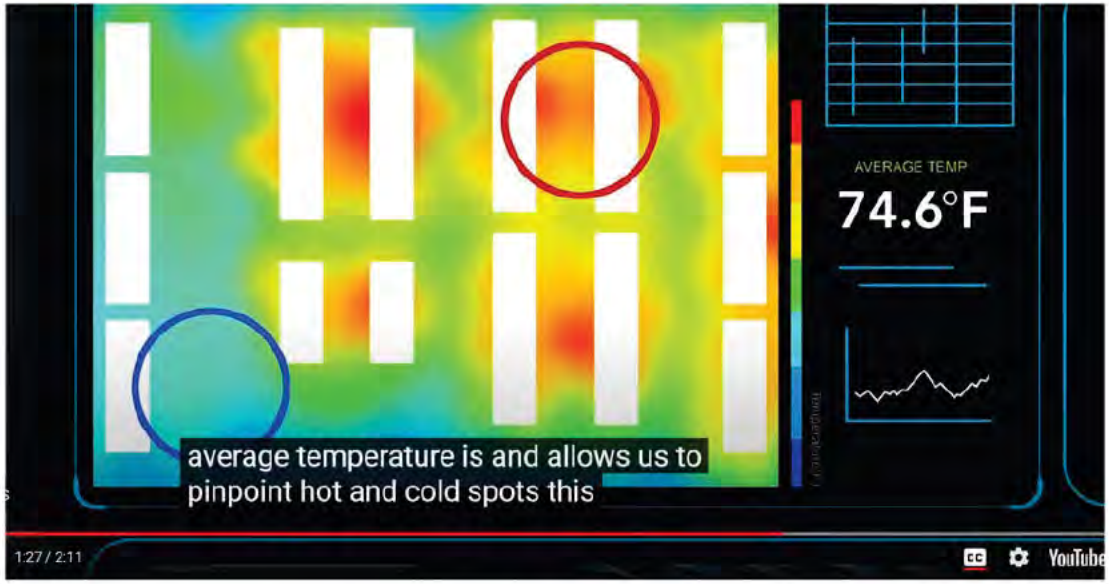
https://www.youtube.com/watch?v=pJutGw7rrF0 at 0:43.

5.1 Preparing for U2U Group Set Up

Cooling units in the network will be assigned to groups, which affects how units function in teamwork, standby, rotation, and cascading operations. Especially in large rooms, it is important to consider several factors before setting up groups to balance cooling unit operation with room conditions.

NOTE: For ease of set-up and use, we recommend using only one group unless you have multiple rooms, differing software versions, or different types of cooling units.

1. Make a map of the room and indicate the location of all heat-generating devices and cooling units to plan for proper heat load management and cooling-air distribution.
2. Note the type of units by product/model, size, etc.
3. Determine the number of units to network together to ensure proper air flow and environmental control, up to 32 units.
4. Determine number of standby units.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	iCOM Manual at p. 94. CyrusOne also uses CyrusOne cooling to generate a 3D temperature map based on real sensor readings retrieved throughout the data center. CyrusOne cooling processes temperature inputs from the sensing step and produces output in the form of a data center temperature map, which can be viewed as a calculated or measured map.  https://www.cyrusone.com/data-center-solutions/colocation, at 1:27;
[1d] comparing said empirical atmospheric map to a template atmospheric map; and	CyrusOne compares said empirical atmospheric map to a template atmospheric map. For example, CyrusOne uses Liebert iCOM. Liebert iCOM compares an empirical atmospheric map to a template atmospheric map, for instance by comparing current temperatures to template setpoints.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

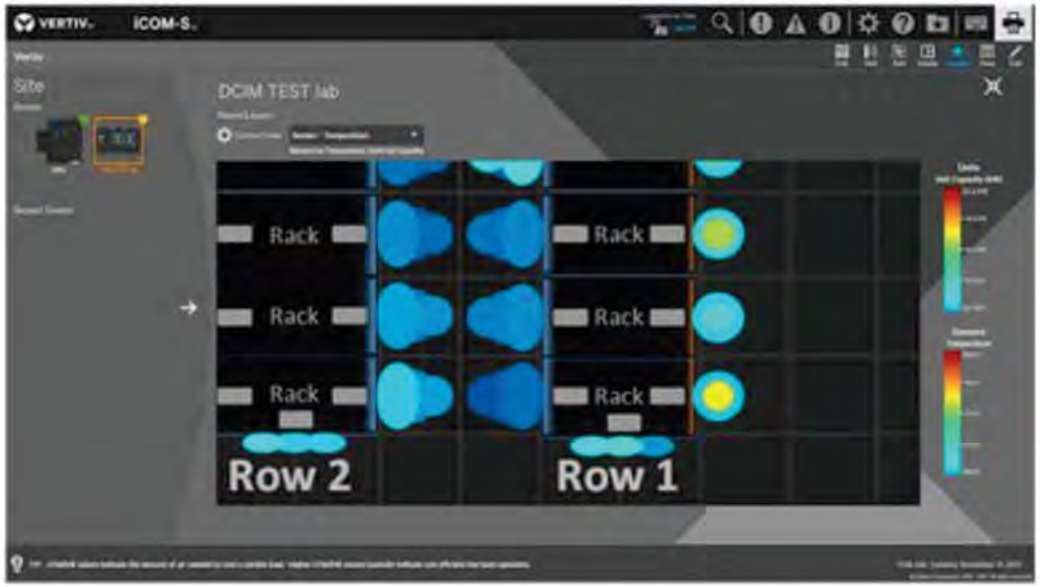
2.4 Viewing Sensor Data

The Sensor Data panel lists the standard and optional sensors monitored by iCOM™and the current reading of each sensor.

- Touch , then  > *Sensor Data*. The SENSOR DATA panel opens.

  A secondary panel displays the DAILY SENSOR READING SUMMARY, which shows temperature, humidity and dew-point readings for the cooling unit.

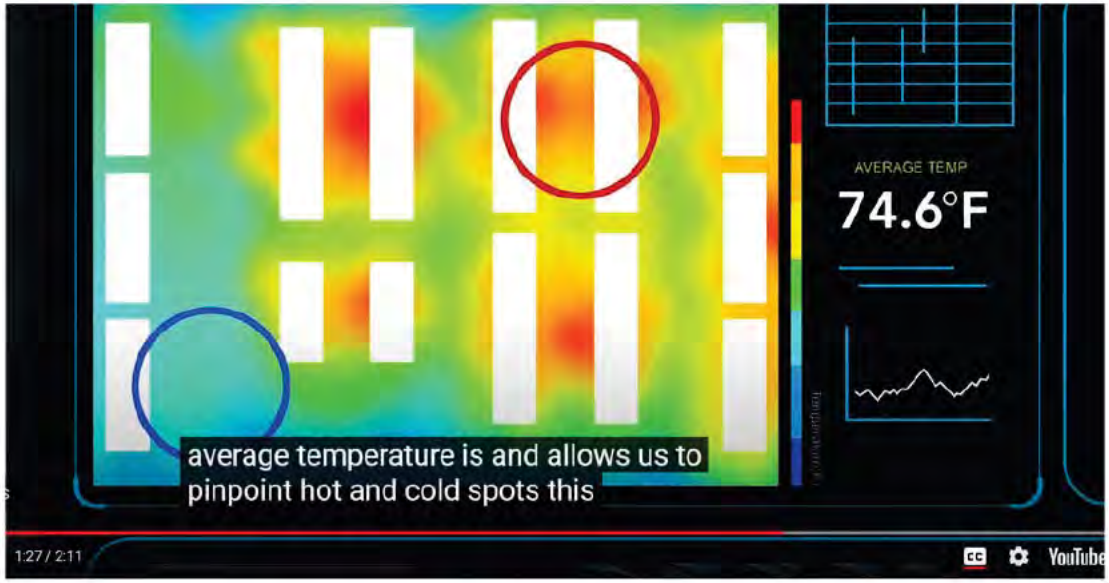
iCOM Manual at p. 20.



https://www.dksh.com/global-en/products/iot/vertiv-thermal-control-and-monitoring

CyrusOne also uses CyrusOne cooling to generate a 3D temperature map based on real sensor readings retrieved throughout the data center. The data center temperature map

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	can be viewed as a calculated or measured map. The measured map can be compared against a template map.  https://www.cyrusone.com/data-center-solutions/colocation , at 1:27;
[1e] identifying pattern differentials between said empirical and template atmospheric maps.	CyrusOne identifies pattern differentials between said empirical and template atmospheric maps. CyrusOne uses Liebert iCOM. Liebert iCOM identifies pattern differentials between the empirical and template maps, for example, by identifying when sensors are reporting conditions that exceed template conditions.

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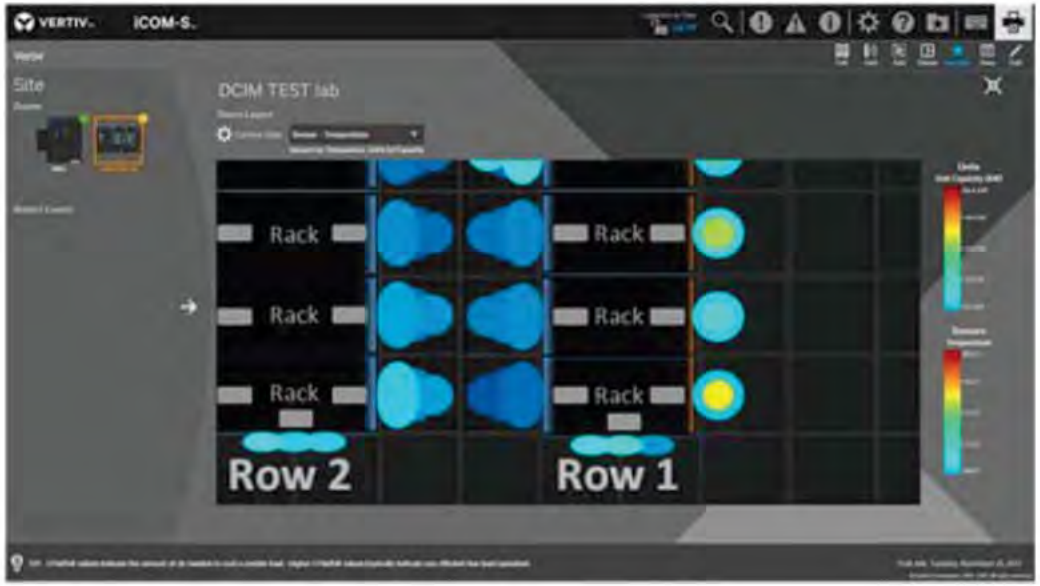
Claim 1	Exemplary Evidence of Infringement by CyrusOne

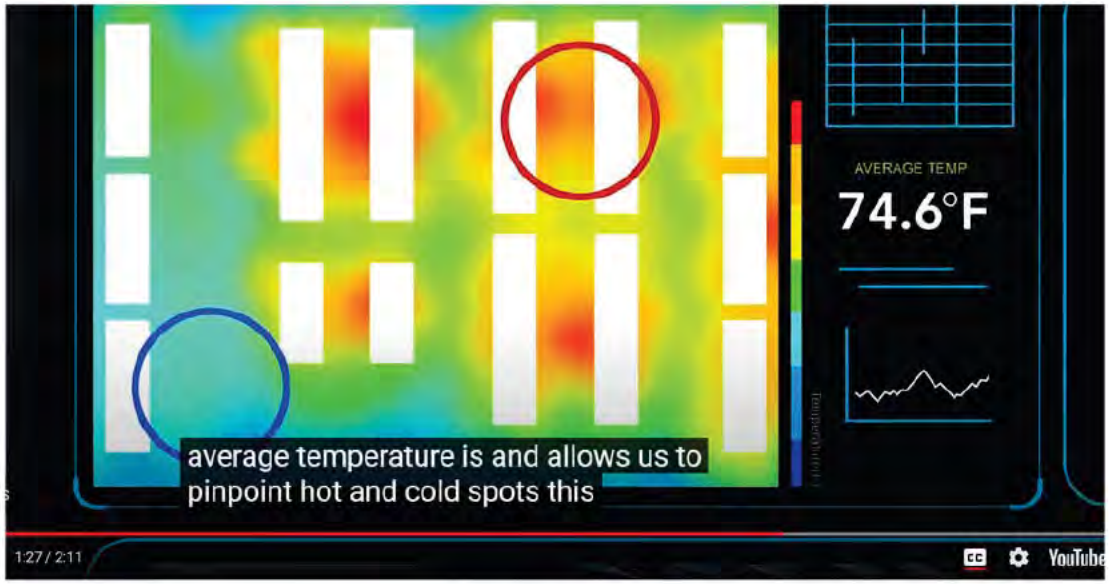
4.2 Enabling Events and Editing Event Settings

In the ALARMS & EVENTS panel, events are grouped into categories for easier management, for example, the factory set remote sensor alarms and humidification/dehumidification events. In some cases, touch the group heading provides edit options for the entire group, like thresholds, delays and enable/disable. Each event includes settings specific for that event and the notification option where event type and alarm notifications are selected (See Selecting Event Type and Setting Alarm/Warning Notification on the facing page).

1. Touch SERVICE, then ☰ > *Alarm/Event Setup*. The ALARMS & EVENTS panel opens.
2. Scroll or search to find the event, touch the set's heading to display theproperties and values for the entire set in the EDIT panel.
   – or –
   Touch an individual alarm or event to display it's specific values in the EDIT panel.

iCOM Manual at p. 80.



Claim 1	Exemplary Evidence of Infringement by CyrusOne
	https://www.dksh.com/global-en/products/iot/vertiv-thermal-control-and-monitoring CyrusOne also uses CyrusOne cooling to generate a 3D temperature map based on real sensor readings retrieved throughout the data center. CyrusOne cooling determines if there is a failure indication of the effectiveness of the active cooling configuration, which shows pattern differentials between the empirical and template atmospheric maps.  https://www.cyrusone.com/data-center-solutions/colocation, at 1:27.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.cyrusone.com/data-center-solutions/colocation , at 0:59.

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Exhibit 9

U.S. Patent No. 6,854,287 – Infringement Claim Chart

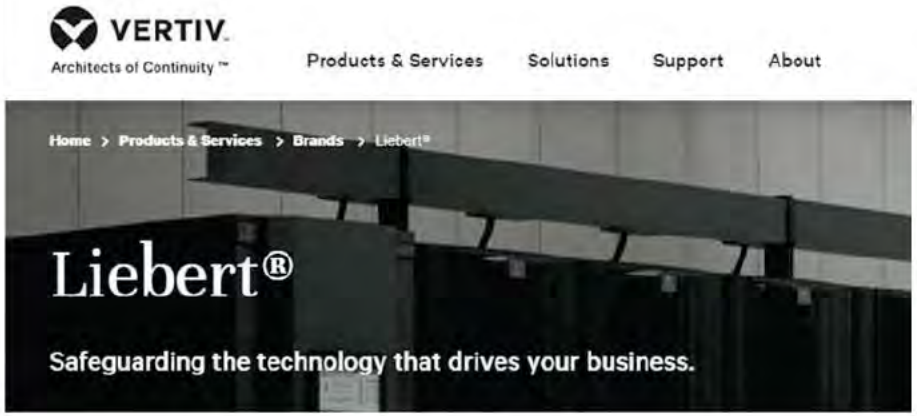
Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1pre] A method for cooling a room configured to house a plurality of computer systems, said method comprising:	CyrusOne's data centers use a method for cooling a room configured to house a plurality of computer systems. For example, CyrusOne uses Vertiv (Liebert) CRAC units in each colocation data center. Liebert CRAC units are controlled by Liebert's iCOM Intelligent Communication and Monitoring system.  https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

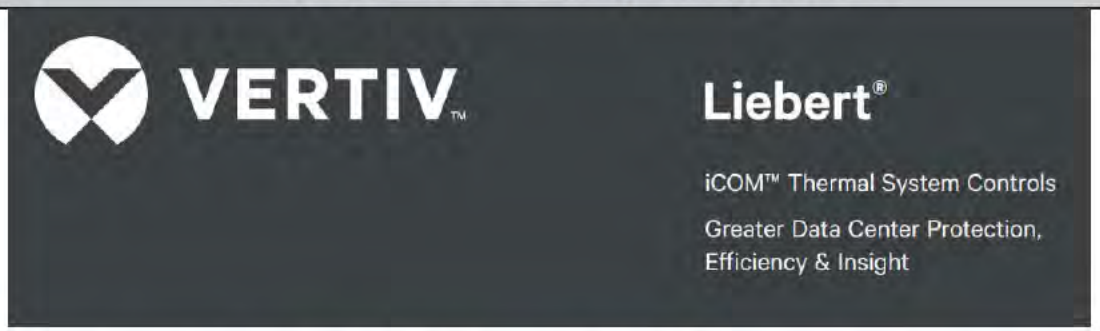
Cooling

- N+1 Cooling
- Redundant DX and Glycol Chillers
- Redundant raised floor CRAC units
- 12in Raised floor

https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.



https://www.vertiv.com/en-us/products/brands/liebert/

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.vertiv.com/49d637/globalassets/shared/liebert-icom-thermal-system-controls-brochure.pdf ("iCOM Brochure").

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	At the cooling unit level, the Liebert iCOM unit control provides the highest protection available and optimal performance. • Monitors 380 unit and component points to eliminate single points of failure • Self-healing features avoid passing unsafe operating thresholds • Highly intuitive, full-color, touch screen simplifies operations to save time and reduce human error • Multiple, automated unit protection routines, including lead/lag, cascade, rapid restart, refrigerant protection and valve calibration  **At the supervisory level,** the Liebert iCOM-S system control offers a revolutionary way to harmonize and optimize thermal system performance to optimize capacity across the data center, gain quick access to actionable data, and automate system diagnostics and trending. • Advanced monitoring and at-a-glance reporting on performance metrics and trends for efficiency, capacity and adverse events • Up to 50% system efficiency gains • 30% lower deployment costs • Teamwork modes that prevent conflict between units and allow them to adapt to changes in facility and IT demand to improve efficiency and availability and reduce system wear and tear – saving more than $10,000 per unit per year in energy costs • Simple and easy to deploy — auto-configuration to detect and configure up to 4,800 sensors, eliminating the need for custom integration to building management systems and cutting sensor deployment times in half  Liebert iCOM unit control and Liebert iCOM-S system control are available for new Vertiv™ data center cooling units or as retrofits. iCOM Brochure at p. 3.
[1a] providing a plurality of heat exchanger units configured to receive air from said room and to deliver air to said room;	CyrusOne provides a plurality of heat exchanger units configured to receive air from said room and to deliver air to said room. For example, CyrusOne uses Liebert CRAC units which are heat exchangers that receive air from the room and deliver cool conditioned air to the room by transferring heat from the air to a fluid.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne

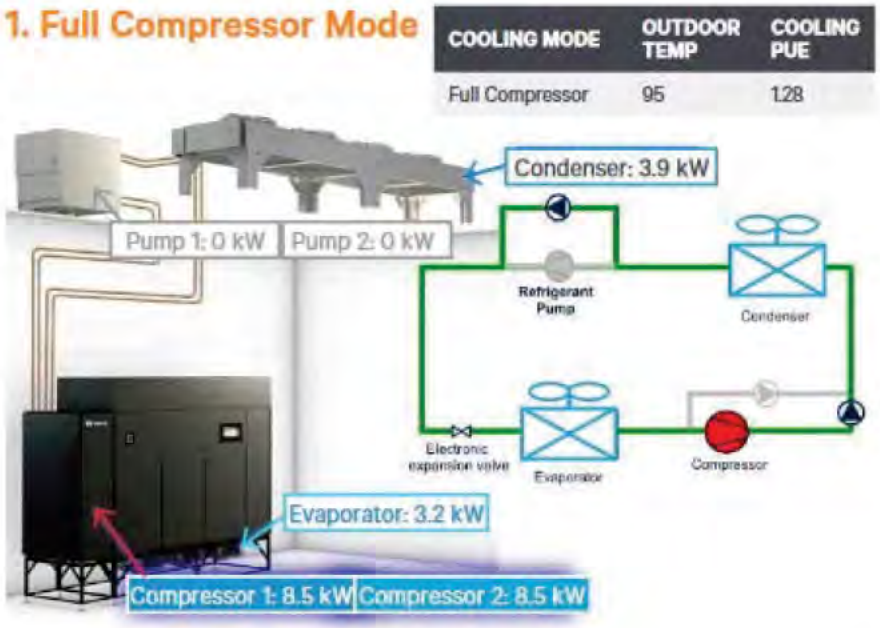


https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.

Cooling

- N+1 Cooling
- Redundant DX and Glycol Chillers
- Redundant raised floor CRAC units
- 12in Raised floor

https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1b] supplying said plurality of heat exchanger units with cooling fluid from an air conditioning unit;	CyrusOne supplies said plurality of heat exchanger units with cooling fluid from an air conditioning unit. For example, CyrusOne uses Liebert's CRAC units which have an evaporator. Refrigerant cooling fluid flows through heat exchanger coils in evaporator.  https://www.vertiv.com/49f1fd/globalassets/products/thermal-management/room-cooling/liebert-dse-sales-brochure-sl-18927_00.pdf. CyrusOne uses Liebert CRAC units which have a chilled water control valve. Chilled water cooling fluid flows through heat exchanger coils in evaporator.

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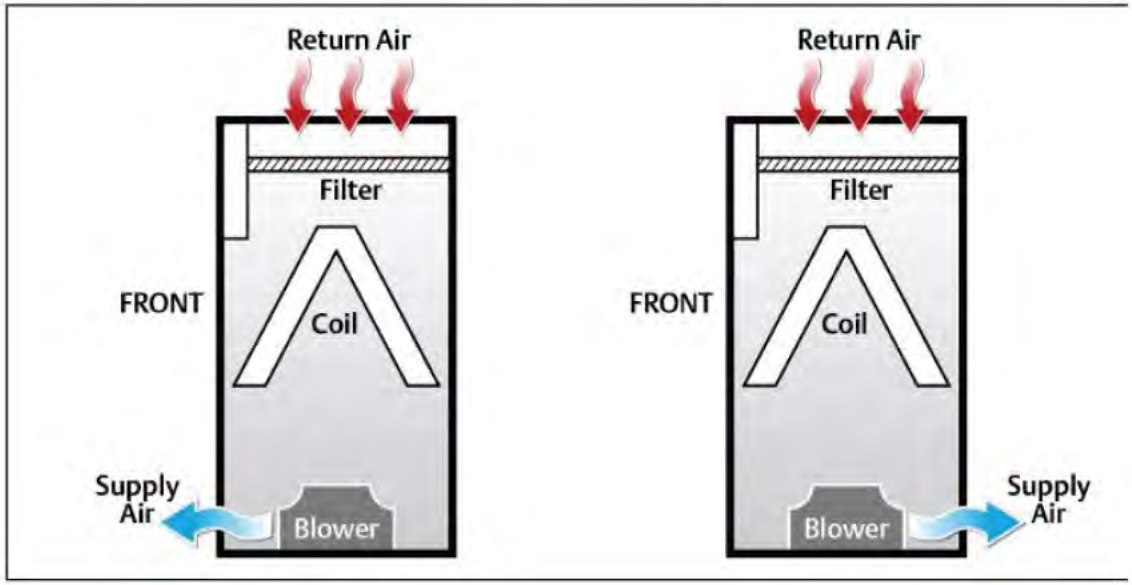
g capacities,

ns.

Chilled Water Control Valve

The chilled water valve provides proportional control action in response to room temperature and humidity as sensed by the microprocessor control. It includes operating linkage and electronic motor. Unlike other systems of this nature it requires no over-travel linkage or end switches to be adjusted. The control uses "intelligent logic" to eliminate valve hunting, thus greatly increasing the life of the valve. The valve can be a 3-way or 2-way to meet the appropriate requirements of the installed system.



Claim 1	Exemplary Evidence of Infringement by CyrusOne
	https://www.vertiv.com/491dda/globalassets/products/thermal-management/room-cooling/liebert-cw-brochure.pdf.
[1c] cooling said received air through heat exchange with the cooling fluid in the plurality of heat exchanger units;	CyrusOne cools said received air through heat exchange with the cooling fluid in the plurality of heat exchanger units. For example, CyrusOne uses Liebert CRAC units to cool fluid (refrigerant) through the coil. The cooling fluid through the coil is chilled water/glycol. Liebert CRAC units receive the "return air" from the room and deliver cool conditioned "supply air" to the room, by transferring heat from the air to the cooling fluid within the coil. 

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	https://www.vertiv.com/4afe7d/globalassets/products/thermal-management/room-cooling/liebert-dse-80-165kw-23-43-tons-downflow-system-design-manual.pdf, pp. 3, 6.
[1d] sensing temperatures at one or more locations in said room;	CyrusOne senses temperatures at one or more locations in said room. For example, CyrusOne uses Liebert CRAC units and the Liebert CRAC unit control system senses temperatures at the supply sensor, remote sensor, or return sensor locations. **3.1.12 Automatic Fan Speed Control** Temperature sensors can control fan speed using one of three modes based on the type of sensor selected as the fan-control sensor: supply, return, or remote, see **Table 3.2** below. Control is based on the selected sensor for both fan control and temperature control and their setpoints as follows: • Coupled: The fan control and temperature control sensor selection is the same. When coupled, fan speed is determined by the temperature setpoints. • Decoupled: The fan control and temperature control sensor selection is different. When decoupled, fan speed is determined by the fan setpoints. **Table 3.2 Fan Speed Controlling Sensor Options** https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 45.

		Temperature Control Sensor Selected		
		Supply Sensor	Remote Sensor	Return Sensor
Fan Control Sensor Selected	Supply Sensor	Coupled	N/A	N/A
	Remote Sensor	Decoupled (Recommended)	Coupled	N/A
	Return Sensor	Decoupled	Decoupled	Coupled

Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1e] controlling at least one of the temperature of said cooling fluid and said air delivery by said plurality of heat exchanger units to said room in response to said sensed temperatures at said one or more locations; and	CyrusOne controls at least one of the temperature of said cooling fluid and said air delivery by said plurality of heat exchanger units to said room in response to said sensed temperatures at said one or more locations. For example, CyrusOne uses Liebert CRAC units which have temperate sensors that control fan speed in response to sensed temperatures. **3.1.12 Automatic Fan Speed Control** Temperature sensors can control fan speed using one of three modes based on the type of sensor selected as the fan-control sensor: supply, return, or remote, see **Table 3.2** below. Control is based on the selected sensor for both fan control and temperature control and their setpoints as follows: • Coupled: The fan control and temperature control sensor selection is the same. When coupled, fan speed is determined by the temperature setpoints. • Decoupled: The fan control and temperature control sensor selection is different. When decoupled, fan speed is determined by the fan setpoints. **Table 3.2 Fan Speed Controlling Sensor Options** https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 45. The Liebert cooling unit controls activates the flow of chilled water/glycol, and varies cooling capacity by adjusting a motorized ball valve.

		Temperature Control Sensor Selected		
		Supply Sensor	Remote Sensor	Return Sensor
Fan Control Sensor Selected	Supply Sensor	Coupled	N/A	N/A
	Remote Sensor	Decoupled (Recommended)	Coupled	N/A
	Return Sensor	Decoupled	Decoupled	Coupled

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	7.1.4 Temperature Control with a Fluid Economizer When an economizer is installed, the cooling requirement (determined by the temperature proportional band) is addressed first by the economizer's secondary cooling. If the economizer cooling capacity is insufficient, the compressor(s) begin cooling to bring the room air temperature down to the temperature setpoint. The fluid economizer employs a motorized ball valve that controls the flow of chilled water/glycol to provide a cooling capacity from 0% to 100%. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 110.
[1f] wherein the step of controlling said air delivery by said plurality of heat exchanger units comprises individually manipulating a mass flow rate of the cooling fluid supplied to each of the plurality of heat exchanger units.	CyrusOne controls said air delivery by said plurality of heat exchanger units comprises individually manipulating a mass flow rate of the cooling fluid supplied to each of the plurality of heat exchanger units. For example, CyrusOne uses Liebert CRAC units which have Teamwork mode. Teamwork mode evaluates changes in the air temperature of the inlet, outlet, or supply temperature of the heat dissipating devices and adjusts one or more cooling units controls to provide the required cooling capacity. **6 Teamwork, Standby and Rotation for Cooling Units** U2U communication via private network and additional hardware (see U2U Networking on page 95) allows the following operating features for the cooling units: • Teamwork • Standby (Rotation) • Cascade https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 99.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	6.2.3 Teamwork Mode 1—Parallel Operation In Teamwork mode 1, fan speed and cooling capacity are ramped up in parallel, which means that all units operate identically. Teamwork mode 1 is best for small rooms with balanced heat loads. A master unit collects the controlling readings for temperature and humidity from all the operating (fan on) units in the group, then determines the average or worst-case reading, and sends operating instructions to efficiently distribute cooling capacity across available units. In Teamwork mode 1, most parameters are shared and, when set in any unit, are set in all units in the group. **6.2.4 Teamwork Mode 2—Independent Operation** Teamwork mode 2 works well for most applications, and best in large rooms with un-balanced heat loads by preventing units in a group from operating in opposing modes, some cooling and some heating. All temperature and humidity parameters are shared by the group. The master unit monitors all available unit-sensor readings and determines the demand for cooling, heating, humidification and dehumidification, then sends operating instructions to address the greatest demand. In Teamwork mode 2, the setpoints for all units must be identical. The proportional band, deadband, and related settings may differ by unit. Fan speed is modulated per unit. Rotation and cascading is not available, so expect uneven distribution of work hours. **6.2.5 Teamwork Mode 3—Optimized Aisle Operation** In Teamwork Mode 3, the fan speed for all units operates in parallel, which means fan speed operation is identical at each unit. However, cooling capacity operates independently for each unit. Teamwork mode 3 takes advantage of variable speed fan options and variable capacity component options to maintain rooms with an unbalanced load and to prevent units in a group from operating in opposing modes. All units operate in the same mode based on the average or worst case (maximum) readings from the unit sensors. A local control (cooling capacity supply sensor) provides input to manage and maintain the discharge-air temperature at each unit. In addition, fan speed and operation are controlled based on readings from the unit temperature or static pressure sensors to control air delivery to the cold aisle. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 102. The Liebert CRAC units also have standby mode. Standby mode evaluates changes in the air temperature of the inlet, outlet, or supply temperature of the heat dissipating devices and actives/de-actives one or more cooling units to provide the required cooling capacity.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	6.3 Assigning Cooling Units to Standby (Lead/Lag) Standby assigns some units to operate while others are on standby, meaning a unit is idle but ready to become active in the event of an alarm condition in one of the operating units or based on a rotation schedule. When a unit is in standby mode, fan(s) are off and no cooling occurs. In multiple cooling unit systems, assigning units to standby lets you: • Configure redundancy in case of failure scenarios (standby). • Manage cooling unit run time (lead/lag). See Setting a Rotation Schedule on the next page . • Modulate for very low loads to full design load (to be temperature reactive) by cascading activation of standby units (configured when setting up teamwork mode). https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 103.

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Exhibit 10

U.S. Patent No. 6,862,179 – Infringement Claim Chart

Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1pre] A method of cooling a plurality of racks in a data center, said method comprising:	CyrusOne's data centers use a method of cooling a plurality of racks in a data center. For example, CyrusOne uses Vertiv (Liebert) downflow chilled water CRAC units in the colocation data center. Liebert CRAC units are controlled by Liebert's iCOM Intelligent Communication and Monitoring system.  https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.



https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.



https://www.vertiv.com/49d637/globalassets/shared/liebert-icom-thermal-system-controls-brochure.pdf ("iCOM Brochure").

At the cooling unit level, the Liebert iCOM unit control provides the highest protection available and optimal performance.

- Monitors 380 unit and component points to eliminate single points of failure
- Self-healing features avoid passing unsafe operating thresholds
- Highly intuitive, full-color, touch screen simplifies operations to save time and reduce human error
- Multiple, automated unit protection routines, including lead/lag, cascade, rapid restart, refrigerant protection and valve calibration



At the supervisory level, the Liebert iCOM-S system control offers a revolutionary way to harmonize and optimize thermal system performance to optimize capacity across the data center, gain quick access to actionable data, and automate system diagnostics and trending.

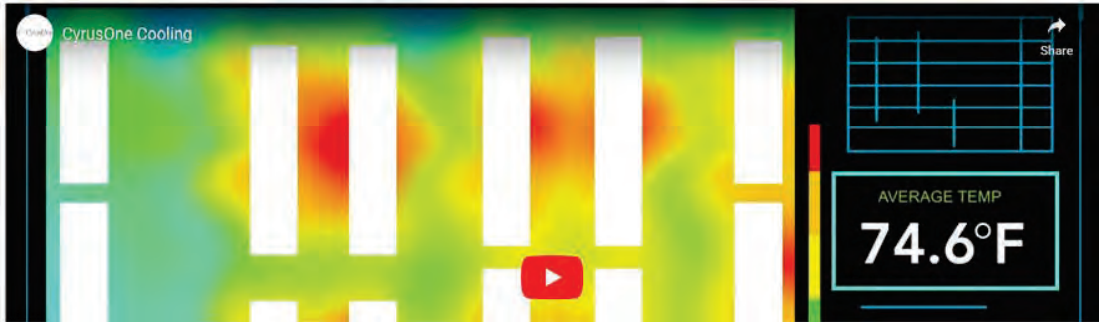
- Advanced monitoring and at-a-glance reporting on performance metrics and trends for efficiency, capacity and adverse events
- Up to 50% system efficiency gains
- 30% lower deployment costs
- Teamwork modes that prevent conflict between units and allow them to adapt to changes in facility and IT demand to improve efficiency and availability and reduce system wear and tear – saving more than $10,000 per unit per year in energy costs
- Simple and easy to deploy — auto-configuration to detect and configure up to 4,800 sensors, eliminating the need for custom integration to building management systems and cutting sensor deployment times in half

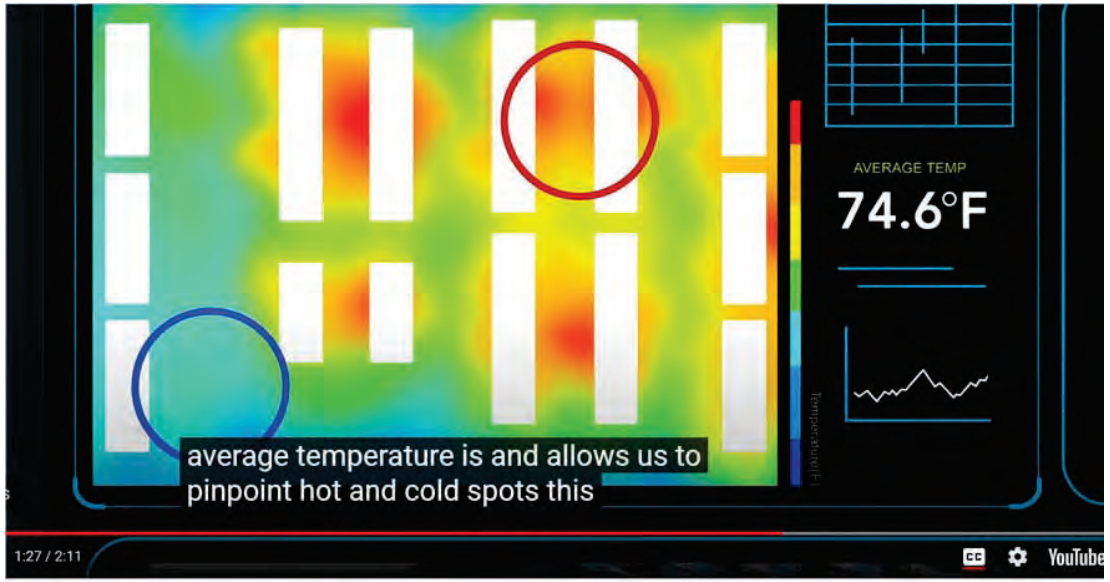


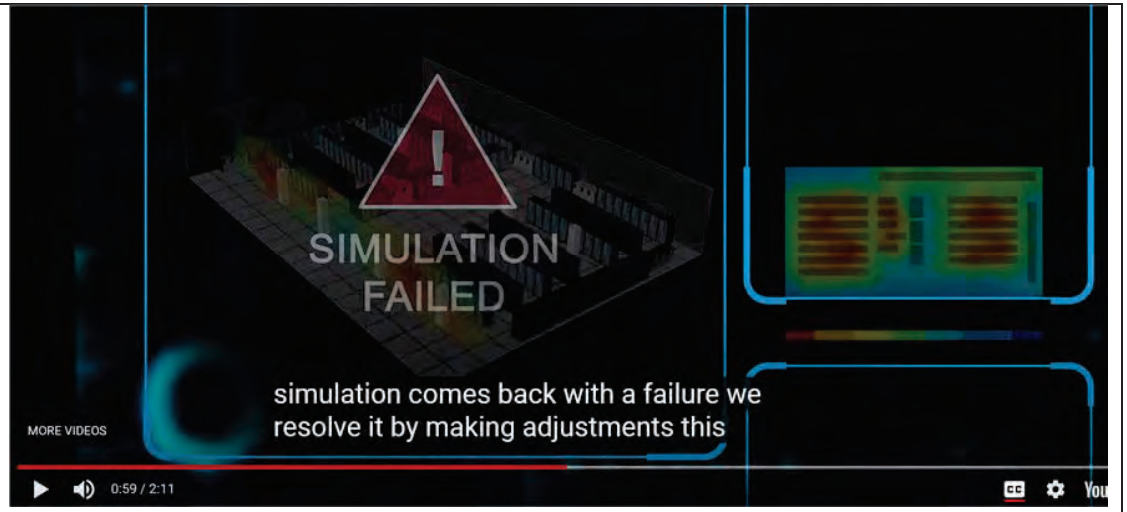
Liebert iCOM unit control and Liebert iCOM-S system control are available for new Vertiv™ data center cooling units or as retrofits.

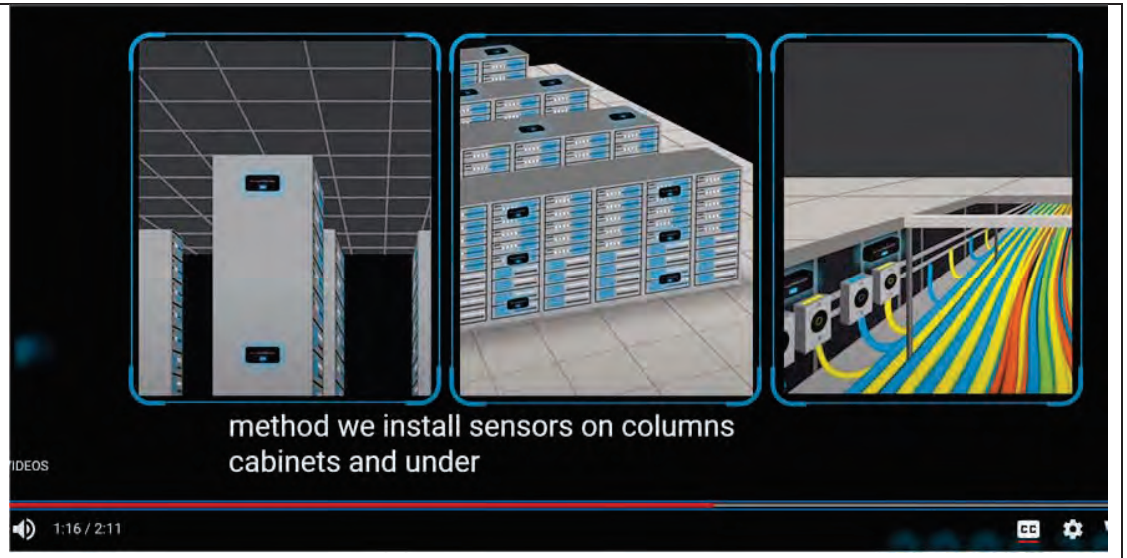
iCOM Brochure at p. 3.

CyrusOne also uses CyrusOne cooling to continuously optimize air flow in its colocation data centers.

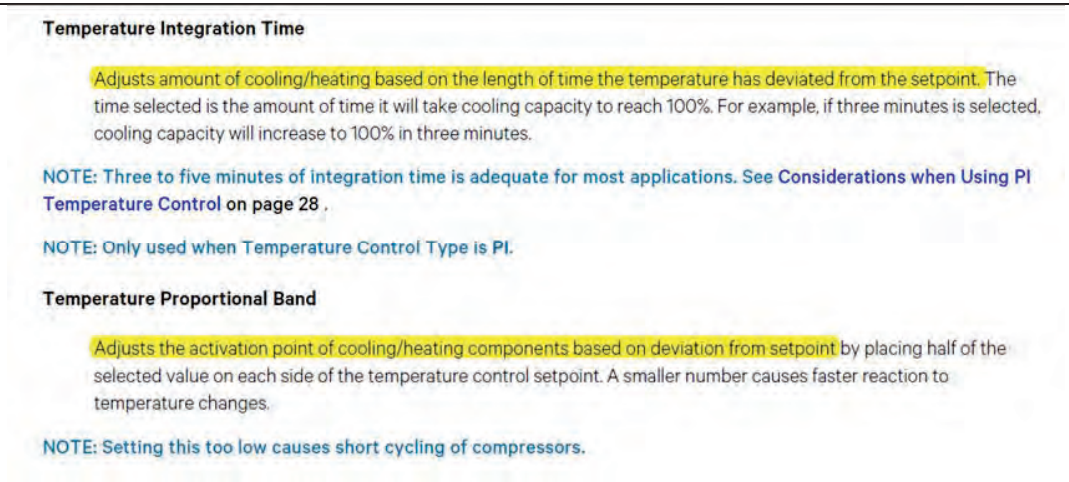
	CyrusOne's data center cooling systems are some of the most advanced in the world employing proactive and reactive methods to keep customer's data halls running at the most optimal temperatures.  https://www.cyrusone.com/data-center-solutions/colocation.
[1a] activating a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks;	CyrusOne activates a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks. For example, Liebert's iCOM Intelligent Communication and Monitoring fluid economizer system activates the flow of chilled water/glycol, and varies cooling capacity by adjusting a motorized ball valve (controllable partition). **7.1.4 Temperature Control with a Fluid Economizer** When an economizer is installed, the cooling requirement (determined by the temperature proportional band) is addressed first by the economizer's secondary cooling, if the economizer cooling capacity is insufficient, the compressor(s) begin cooling to bring the room air temperature down to the temperature setpoint. The fluid economizer employs a motorized ball valve that controls the flow of chilled water/glycol to provide a cooling capacity from 0% to 100%. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 110.

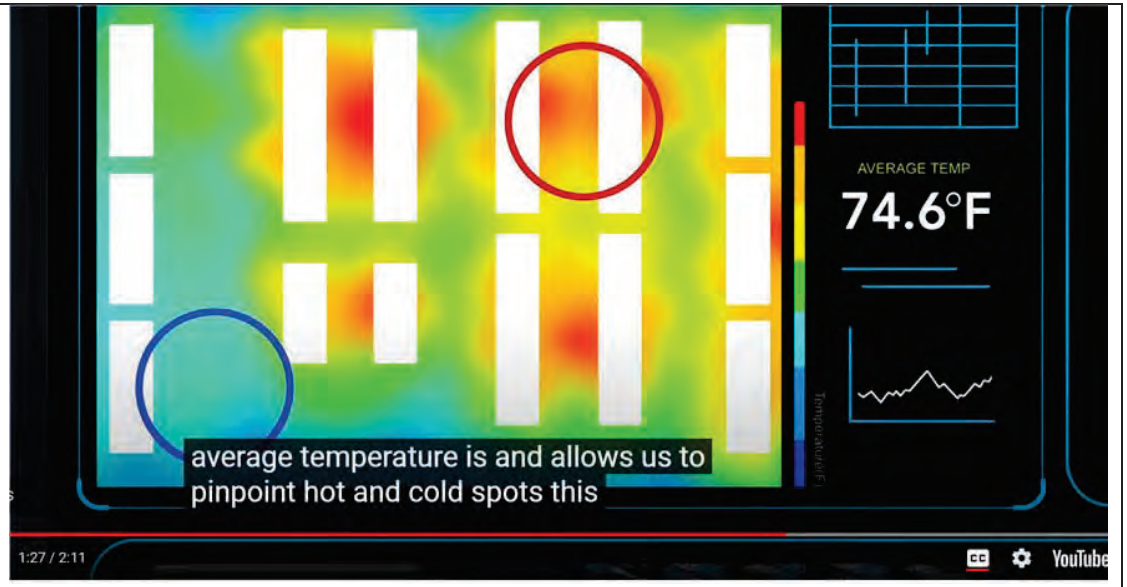
	CyrusOne also uses CyrusOne Cooling which is a closed-loop system that reacts to real-time data, automatically identifies and eliminates hot spots and helps diagnose potential facility risks by making adjustments.  https://www.cyrusone.com/data-center-solutions/colocation, at 1:27.

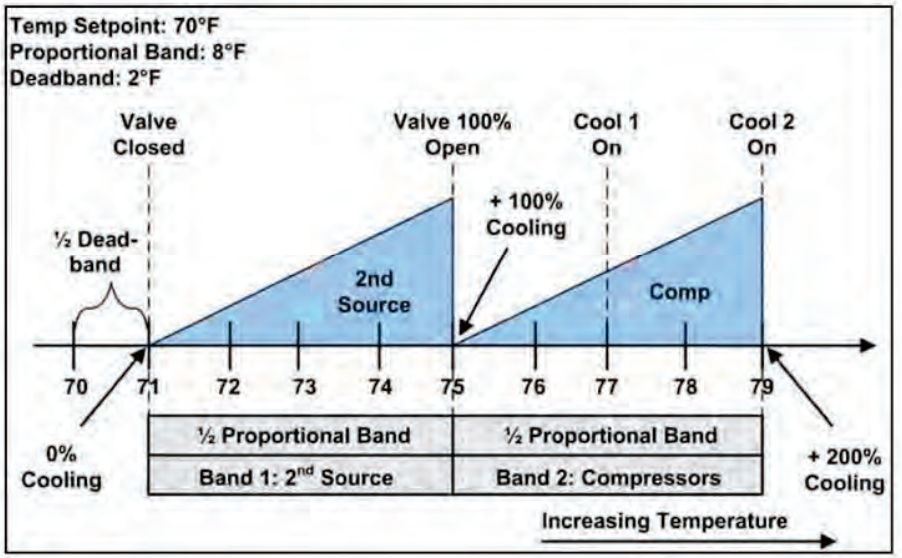
	 https://www.cyrusone.com/data-center-solutions/colocation, at 0:59.
[1b] sensing the temperature of said at least one associated rack;	CyrusOne senses the temperature of said at least one associated rack. For example, CyrusOne uses Liebert cooling units and the Liebert cooling unit control system senses temperatures. **13.2 Installing Wired Remote Sensors** Up to 10 remote sensor modules, installed in the monitored racks and connected to the cooling unit, provide control and reference input to iCOM and building-management systems. Using remote, rack sensors combats cooling problems related to recirculation air, uneven rack loading, and air distribution. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 180. CyrusOne also uses CyrusOne cooling which installs temperature sensors to determine exactly where the heat load is within the data center. Data is wirelessly transmitted to network gateways, aggregated, and sent to a purpose-built appliance where it is analyzed by control software. Control commands are then delivered to the cooling equipment.

	 https://www.youtube.com/watch?v=yFMS-88wXn8, at 1:16.
[1c] determining whether said sensed temperature is within a predetermined temperature range; and	CyrusOne determines whether said sensed temperature is within a predetermined temperature range. For example, CyrusOne uses the Liebert iCOM system which is able to identify if the temperature is at the setpoint value, and change the response to the varied flow field based on length of time temperature has deviated, and amount of deviation from setpoint.

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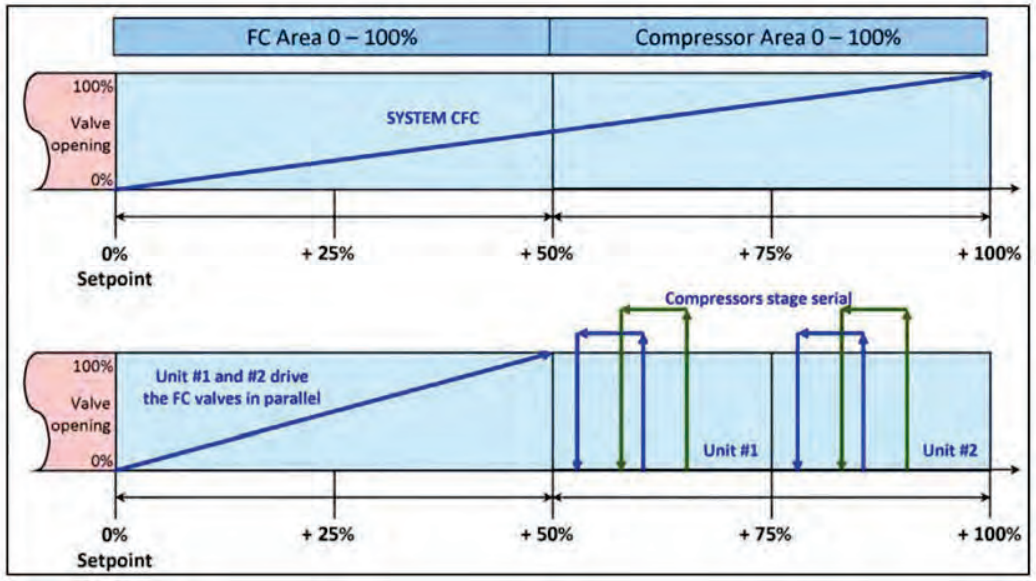
	 **Temperature Integration Time** Adjusts amount of cooling/heating based on the length of time the temperature has deviated from the setpoint. The time selected is the amount of time it will take cooling capacity to reach 100%. For example, if three minutes is selected, cooling capacity will increase to 100% in three minutes. NOTE: Three to five minutes of integration time is adequate for most applications. See **Considerations when Using PI Temperature Control** on page 28 . NOTE: Only used when Temperature Control Type is PI. **Temperature Proportional Band** Adjusts the activation point of cooling/heating components based on deviation from setpoint by placing half of the selected value on each side of the temperature control setpoint. A smaller number causes faster reaction to temperature changes. NOTE: Setting this too low causes short cycling of compressors. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 25. CyrusOne also uses CyrusOne Cooling to determine whether the sensed temperature is within a predetermined temperature range, for example, by using hot and cold spots.

	 https://www.cyrusone.com/data-center-solutions/colocation, at 1:27.
[1d] manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to said sensed temperature being outside said predetermined temperature range.	CyrusOne manipulates said controllable partition to vary said supply of said cooling fluid to said zone in response to said sensed temperature being outside said predetermined temperature range. CyrusOne uses Liebert's iCOM system to manipulate the motorized ball valve (controllable partition) from 0% to 100% flow of chilled water/glycol. **7.1.4 Temperature Control with a Fluid Economizer** When an economizer is installed, the cooling requirement (determined by the temperature proportional band) is addressed first by the economizer's secondary cooling, if the economizer cooling capacity is insufficient, the compressor(s) begin cooling to bring the room air temperature down to the temperature setpoint. The fluid economizer employs a motorized ball valve that controls the flow of chilled water/glycol to provide a cooling capacity from 0% to 100%.

	https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 110. Figure 3.17 Second Cooling Source and Two-Step Compressorized Cooling  https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 69, Fig. 3.17.

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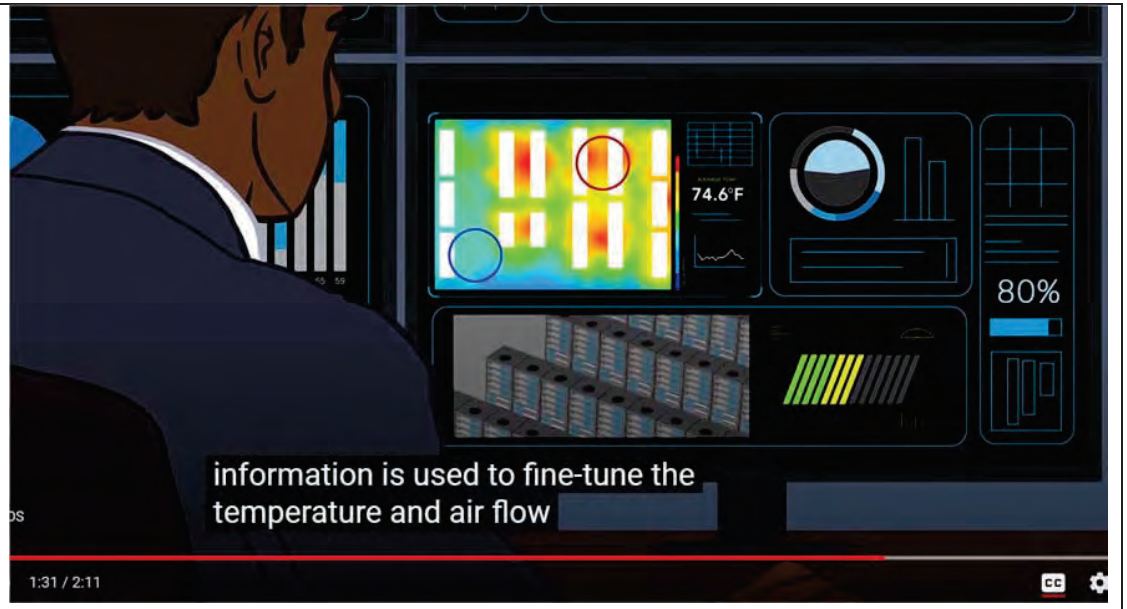
Figure 3.18 Freecooling and Compressorized Operation



https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 70, Fig. 3.18.

CyrusOne also uses CyrusOne Cooling Optimize to adjust cooling output by fine-tuning the air flow.

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	 https://www.cyrusone.com/data-center-solutions/colocation, at 1:31.

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Exhibit 11

U.S. Patent No. 7,031,870 – Infringement Claim Chart

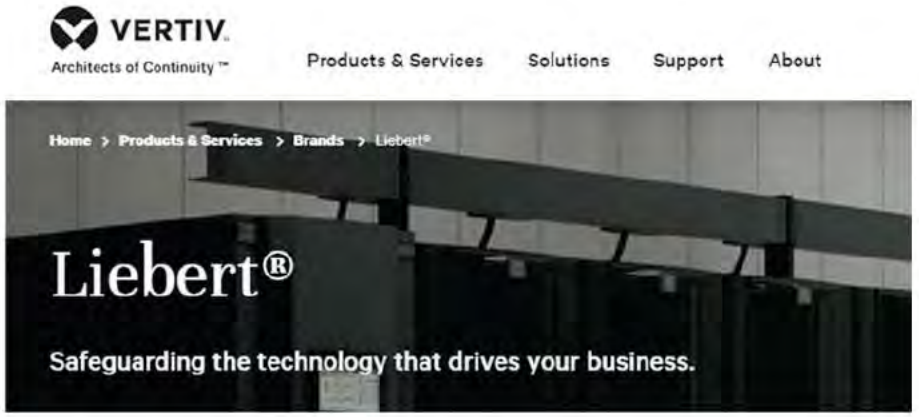
Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1pre] A method for evaluating one or more components in a data center, the method comprising:	CyrusOne's data centers use a method for evaluating one or more components in a data center. For example, CyrusOne uses Vertiv and Liebert cooling in its U.S. data centers to control atmospheric conditions. Liebert's CRAC units are controlled, for example, by Liebert's iCOM and/or iCOM-S Intelligent Communication and Monitoring System, which uses a method for evaluating one or more components in a data center.  https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

Cooling

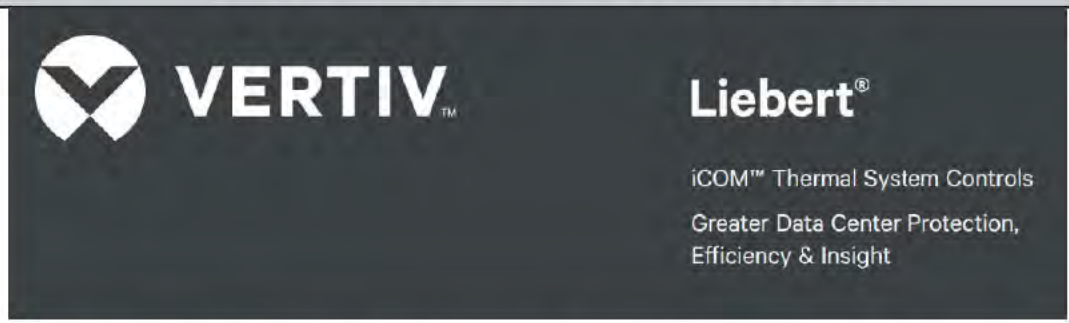
- N+1 Cooling
- Redundant DX and Glycol Chillers
- Redundant raised floor CRAC units
- 12in Raised floor

https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.



https://www.vertiv.com/en-us/products/brands/liebert/.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.vertiv.com/49d637/globalassets/shared/liebert-icom-thermal-system-controls-brochure.pdf ("iCOM Brochure").

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	At the cooling unit level, the Liebert iCOM unit control provides the highest protection available and optimal performance. • Monitors 380 unit and component points to eliminate single points of failure • Self-healing features avoid passing unsafe operating thresholds • Highly intuitive, full-color, touch screen simplifies operations to save time and reduce human error • Multiple, automated unit protection routines, including lead/lag, cascade, rapid restart, refrigerant protection and valve calibration  **At the supervisory level,** the Liebert iCOM-S system control offers a revolutionary way to harmonize and optimize thermal system performance to optimize capacity across the data center, gain quick access to actionable data, and automate system diagnostics and trending. • Advanced monitoring and at-a-glance reporting on performance metrics and trends for efficiency, capacity and adverse events • Up to 50% system efficiency gains • 30% lower deployment costs • Teamwork modes that prevent conflict between units and allow them to adapt to changes in facility and IT demand to improve efficiency and availability and reduce system wear and tear – saving more than $10,000 per unit per year in energy costs • Simple and easy to deploy — auto-configuration to detect and configure up to 4,800 sensors, eliminating the need for custom integration to building management systems and cutting sensor deployment times in half  Liebert iCOM unit control and Liebert iCOM-S system control are available for new Vertiv™ data center cooling units or as retrofits. iCOM Brochure at p. 3.
[1a] detecting inlet and outlet temperatures of one or more heat dissipating devices;	CyrusOne detects inlet and outlet temperatures of one or more heat dissipating devices. CyrusOne uses Liebert iCOM. Liebert iCOM detects inlet and outlet temperatures at server racks using wired, remote rack sensors.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	9.4 Wired Remote Sensors Wired, remote, rack sensors can function as control sensors and subsequently, provide input individually at the unit level or at the system level for temperature control and teamwork functions. Each wired remote rack sensor has two thermistors/probes. In Individual Sensor mode, the higher temperature reading or the average temperature reading of the two probes can be used. In Unit Sensors mode, some or all of the rack sensor's temperature readings are considered for higher (maximum) or average calculation. For example, setting three sensors as control and average for unit mode, averages the three highest temperature readings. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf ("iCOM Manual") at p. 156.
[1b] detecting temperatures of air supplied by one or more computer room air conditioning (CRAC) units;	CyrusOne detects temperatures of air supplied by one or more computer room air conditioning (CRAC) units. CyrusOne uses Liebert iCOM. Liebert iCOM detects temperatures of air supplied by one or more CRAC units. **13.4 Installing Supply Control Sensors** **13.4.1 Installing the Supply Air Temperature Sensor** The supply temperature sensor is connected to P8, Pins 1 and 2 at the factory and requires no configuration. 1. Place the sensor in an area that is influenced only by the unit to which it is connected to provide an accurate reading: 5 ft. to 15 ft. (1.5 m to 4.5 m) from the cooling unit, **Figure 13.16** below. iCOM Manual at p. 191.
[1c] calculating indices of air re-circulation for the one or more heat dissipating devices based upon the detected inlet temperatures, outlet temperatures and supplied air temperatures;	CyrusOne calculates indices of air re-circulation for the one or more heat dissipating devices based upon the detected inlet temperatures, outlet temperatures and supplied air temperatures. CyrusOne uses Liebert iCOM. Liebert iCOM calculates indices of air recirculation for server racks based on detected inlet, outlet, and supplied air temperatures.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

13.2 Installing Wired Remote Sensors

Up to 10 remote sensor modules, installed in the monitored racks and connected to the cooling unit, provide control and reference input to iCOM and building-management systems. Using remote, rack sensors combats cooling problems related to recirculation air, uneven rack loading, and air distribution.

iCOM Manual at p. 180.

13.1 Return Air Temperature/Humidity Sensor

The return temperature/humidity sensor is located in the unit return air section and is supplied on all Liebert®systems with iCOM™ controls. The assembly connects to plug connection P67 on the iCOM internal control board on all CRV systems.

iCOM Manual at p. 179.

13.4 Installing Supply Control Sensors

13.4.1 Installing the Supply Air Temperature Sensor

The supply temperature sensor is connected to P8, Pins 1 and 2 at the factory and requires no configuration.

1. Place the sensor in an area that is influenced only by the unit to which it is connected to provide an accurate reading: 5 ft. to 15 ft. (1.5 m to 4.5 m) from the cooling unit, **Figure 13.16** below.

iCOM Manual at p. 191.

Temperature Control Sensor

Selects sensor that controls cooling. Values are:

- Supply Sensor: Temperature control is based on maintaining the temperature of the discharge air from the cooling unit. See Supply Sensors on page 158.
- Remote Sensor: Temperature control is based on the temperature reading(s) from wired remote/rack sensor(s). See Wired Remote Sensors on page 156.
- Return Sensor: Temperature control is based on maintaining the temperature of the room air.
- Customer input setpoint (remote alarm device)

<table>
<tr><th>Claim 1</th><th>Exemplary Evidence of Infringement by CyrusOne</th></tr>
<tr><td></td><td>iCOM Manual at p. 25.</td></tr>
<tr><td>[1d] varying a flow field setting of air delivered to the one or more heat dissipating devices;</td><td>CyrusOne varies a flow field setting of air delivered to the one or more heat dissipating devices.

CyrusOne uses Liebert iCOM. Liebert iCOM varies the flow field setting of air delivered to server racks by, for example, controlling fan speed.

3.1.12 Automatic Fan Speed Control

Temperature sensors can control fan speed using one of three modes based on the type of sensor selected as the fan-control sensor: supply, return, or remote, see Table 3.2 below. Control is based on the selected sensor for both fan control and temperature control and their setpoints as follows:

• Coupled: The fan control and temperature control sensor selection is the same. When coupled, fan speed is determined by the temperature setpoints.
• Decoupled: The fan control and temperature control sensor selection is different. When decoupled, fan speed is determined by the fan setpoints.

Table 3.2 Fan Speed Controlling Sensor Options

<table><tr><th colspan="2" rowspan="2"></th><th colspan="3">Temperature Control Sensor Selected</th></tr><tr><th>Supply Sensor</th><th>Remote Sensor</th><th>Return Sensor</th></tr><tr><td rowspan="3">Fan Control Sensor Selected</td><td>Supply Sensor</td><td>Coupled</td><td>N/A</td><td>N/A</td></tr><tr><td>Remote Sensor</td><td>Decoupled (Recommended)</td><td>Coupled</td><td>N/A</td></tr><tr><td>Return Sensor</td><td>Decoupled</td><td>Decoupled</td><td>Coupled</td></tr></table>

iCOM Manual at p. 45.</td></tr>
<tr><td>[1e] determining whether the indices of air re-circulation has changed in response to the varied flow field settings; and</td><td>CyrusOne determines whether the indices of air re-circulation has changed in response to the varied flow field settings.

CyrusOne uses Liebert iCOM. Liebert iCOM determines whether the indices of air re-circulation have changed in response to varied flow field settings, by for example</td></tr>
</table>

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	changing the response to varying fan speeds based on the length of time temperature has deviated and the amount of deviation from the setpoint. **Temperature Integration Time** Adjusts amount of cooling/heating based on the length of time the temperature has deviated from the setpoint. The time selected is the amount of time it will take cooling capacity to reach 100%. For example, if three minutes is selected, cooling capacity will increase to 100% in three minutes. **NOTE: Three to five minutes of integration time is adequate for most applications. See Considerations when Using PI Temperature Control on page 28 .** **NOTE: Only used when Temperature Control Type is PI.** **Temperature Proportional Band** Adjusts the activation point of cooling/heating components based on deviation from setpoint by placing half of the selected value on each side of the temperature control setpoint. A smaller number causes faster reaction to temperature changes. **NOTE: Setting this too low causes short cycling of compressors.** iCOM Manual at p. 25.
[1f] evaluating the one or more components based upon changes in the indices of air re-circulation for the one or more heat dissipating devices at the various flow field settings.	CyrusOne evaluates the one or more components based upon changes in the indices of air re-circulation for the one or more heat dissipating devices at the various flow field settings. CyrusOne uses Liebert iCOM. Liebert iCOM evaluates the components based on changed in the indices of air re-circulation for the server racks at various flow field settings. For example, Teamwork Mode evaluates changes in the air temperature of the inlet, outlet, or supply temperature of the heat dissipating devices and adjusts one or more cooling units controls to provide the required cooling capacity, and Standby Mode evaluates these changes and activates/deactivates one or more CRAC units to provide required cooling capacity.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	6 Teamwork, Standby and Rotation for Cooling Units U2U communication via private network and additional hardware (see U2U Networking on page 95) allows the following operating features for the cooling units: • Teamwork • Standby (Rotation) • Cascade iCOM Manual at p. 99.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	6.2.3 Teamwork Mode 1—Parallel Operation In Teamwork mode 1, fan speed and cooling capacity are ramped up in parallel, which means that all units operate identically. Teamwork mode 1 is best for small rooms with balanced heat loads. A master unit collects the controlling readings for temperature and humidity from all the operating (fan on) units in the group, then determines the average or worst-case reading, and sends operating instructions to efficiently distribute cooling capacity across available units. In Teamwork mode 1, most parameters are shared and, when set in any unit, are set in all units in the group. **6.2.4 Teamwork Mode 2—Independent Operation** Teamwork mode 2 works well for most applications, and best in large rooms with un-balanced heat loads by preventing units in a group from operating in opposing modes, some cooling and some heating. All temperature and humidity parameters are shared by the group. The master unit monitors all available unit-sensor readings and determines the demand for cooling, heating, humidification and dehumidification, then sends operating instructions to address the greatest demand. In Teamwork mode 2, the setpoints for all units must be identical. The proportional band, deadband, and related settings may differ by unit. Fan speed is modulated per unit. Rotation and cascading is not available, so expect uneven distribution of work hours. **6.2.5 Teamwork Mode 3—Optimized Aisle Operation** In Teamwork Mode 3, the fan speed for all units operates in parallel, which means fan speed operation is identical at each unit. However, cooling capacity operates independently for each unit. Teamwork mode 3 takes advantage of variable speed fan options and variable capacity component options to maintain rooms with an unbalanced load and to prevent units in a group from operating in opposing modes. All units operate in the same mode based on the average or worst case (maximum) readings from the unit sensors. A local control (cooling capacity supply sensor) provides input to manage and maintain the discharge-air temperature at each unit. In addition, fan speed and operation are controlled based on readings from the unit temperature or static pressure sensors to control air delivery to the cold aisle. iCOM Manual at p. 102.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	6.3 Assigning Cooling Units to Standby (Lead/Lag) Standby assigns some units to operate while others are on standby, meaning a unit is idle but ready to become active in the event of an alarm condition in one of the operating units or based on a rotation schedule. When a unit is in standby mode, fan(s) are off and no cooling occurs. In multiple cooling unit systems, assigning units to standby lets you: • Configure redundancy in case of failure scenarios (standby). • Manage cooling unit run time (lead/lag). See Setting a Rotation Schedule on the next page. • Modulate for very low loads to full design load (to be temperature reactive) by cascading activation of standby units (configured when setting up teamwork mode). iCOM Manual at p. 103.

Exhibit 12

U.S. Patent No. 7,339,490 – Infringement Claim Chart

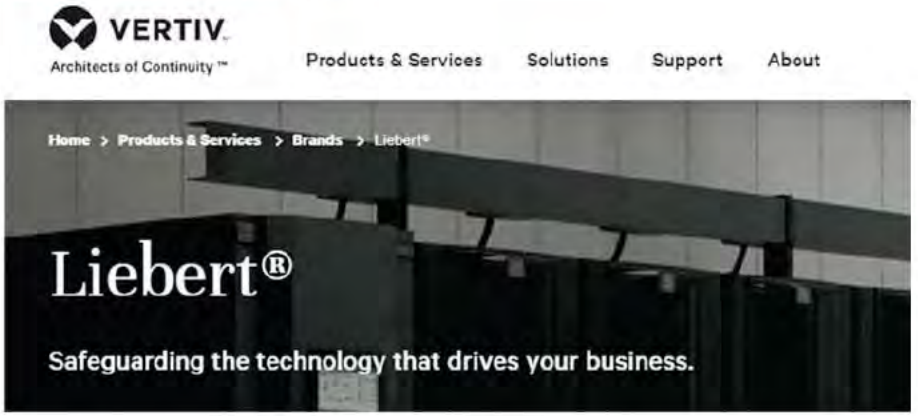
Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1pre] A modular sensor assembly for sensing a condition at a computer rack, comprising:	CyrusOne's data centers use a modular sensor assembly for sensing a condition at a computer rack. For example, CyrusOne uses Vertiv and Liebert cooling in its U.S. data centers to control atmospheric conditions. On information and belief, CyrusOne's Liebert CRAC units are used in conjunction with Liebert's modular sensors, which are used to sense conditions such as temperature, humidity, and door-open status at a computer rack.  https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

Cooling

- N+1 Cooling
- Redundant DX and Glycol Chillers
- Redundant raised floor CRAC units
- 12in Raised floor

https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.



https://www.vertiv.com/en-us/products/brands/liebert/.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne

LIEBERT® SN™
MODULAR SENSORS
Quick Installation Guide

VERTIV.

The Liebert SN modular sensors monitor temperature, humidity, door-open status, and digital input, such as smoke or water, in any area.

These instructions apply to the following Liebert SN modular-sensor models:

- SN-T—1 temperature probe
- SN-TH—1 temperature probe and 1 humidity probe
- SN-2D—1 door-switch probe with 2 inputs
- SN-3C—1 digital-input probe with 3 inputs

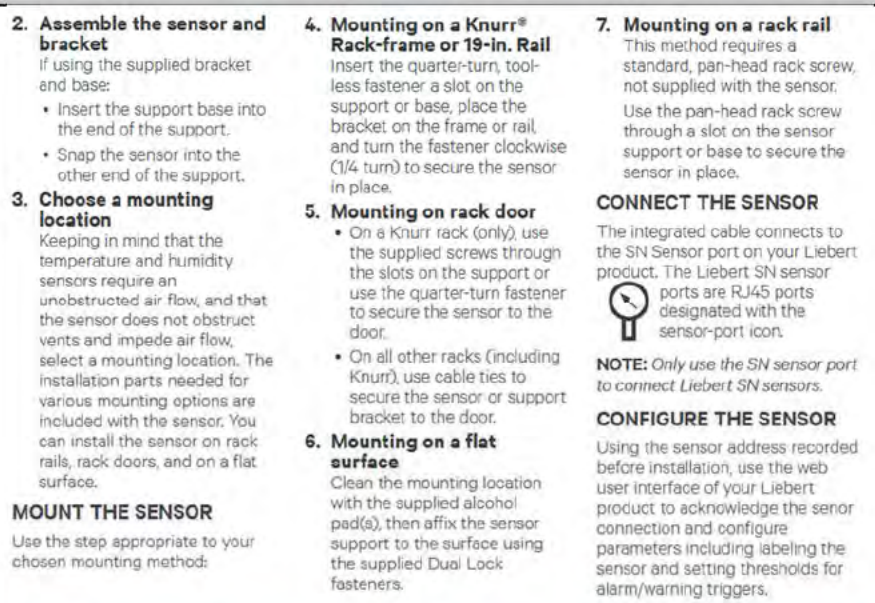
Each modular sensor ships with a 6.6-ft (2-m) cable to connect with a Liebert monitoring product.

SENSOR-STRING COMPATIBLE

You can attach the sensors in a

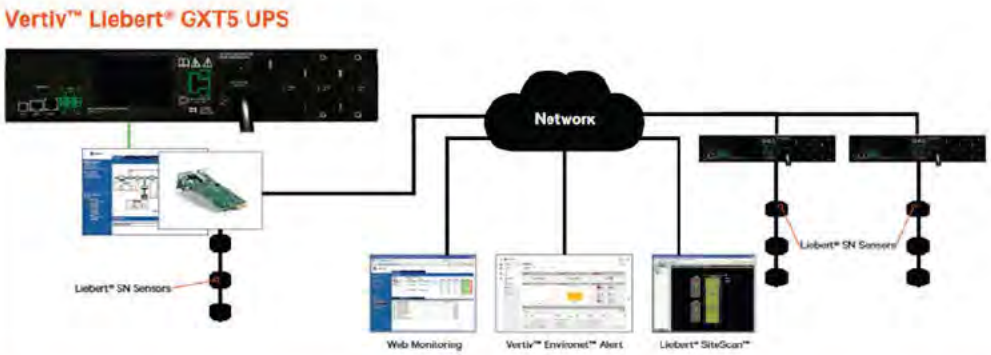
Liebert Sensors, Cable and Mount



Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 **2. Assemble the sensor and bracket** If using the supplied bracket and base: • Insert the support base into the end of the support. • Snap the sensor into the other end of the support. **3. Choose a mounting location** Keeping in mind that the temperature and humidity sensors require an unobstructed air flow, and that the sensor does not obstruct vents and impede air flow, select a mounting location. The installation parts needed for various mounting options are included with the sensor. You can install the sensor on rack rails, rack doors, and on a flat surface. **MOUNT THE SENSOR** Use the step appropriate to your chosen mounting method: **4. Mounting on a Knurr® Rack-frame or 19-in. Rail** Insert the quarter-turn, tool-less fastener a slot on the support or base, place the bracket on the frame or rail, and turn the fastener clockwise (1/4 turn) to secure the sensor in place. **5. Mounting on rack door** • On a Knurr rack (only), use the supplied screws through the slots on the support or use the quarter-turn fastener to secure the sensor to the door. • On all other racks (including Knurr), use cable ties to secure the sensor or support bracket to the door. **6. Mounting on a flat surface** Clean the mounting location with the supplied alcohol pad(s), then affix the sensor support to the surface using the supplied Dual Lock fasteners. **7. Mounting on a rack rail** This method requires a standard, pan-head rack screw, not supplied with the sensor. Use the pan-head rack screw through a slot on the sensor support or base to secure the sensor in place. **CONNECT THE SENSOR** The integrated cable connects to the SN Sensor port on your Liebert product. The Liebert SN sensor ports are RJ45 ports designated with the sensor-port icon. **NOTE:** *Only use the SN sensor port to connect Liebert SN sensors.* **CONFIGURE THE SENSOR** Using the sensor address recorded before installation, use the web user interface of your Liebert product to acknowledge the senor connection and configure parameters including labeling the sensor and setting thresholds for alarm/warning triggers. https://www.vertiv.com/49782f/globalassets/shared/liebert-sn-modular-sensors-quick-start-guide_00.pdf.
[1a] a) an elongate flexible body, configured to attach to a computer rack;	CyrusOne's modular sensor assemblies comprise an elongate flexible body, configured to attach to a computer rack. CyrusOne uses Liebert CRAC units with Liebert sensors. Liebert modular sensors attached in a strong consist of an elongate flexible body that attaches to a computer rack frame, rail, or door.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	SENSOR-STRING COMPATIBLE You can attach the sensors in a string, and the string can be a combination of integrated and modular sensors. (Integrated sensors are one or more probes integrated on a single cable.) A string may include up to 10 probes and be a maximum of 65.6 ft (20 m). The number of probes that may be used with Liebert monitoring products varies. Refer to the product's user guide for details. https://www.vertiv.com/49782f/globalassets/shared/liebert-sn-modular-sensors-quick-start-guide_00.pdf.

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Claim 1	Exemplary Evidence of Infringement by CyrusOne
	Vertiv™ Liebert® SN Sensors VERTIV  https://www.vertiv.com/4a84b9/globalassets/shared/liebert-sn-sensors-monitoring-for-business-critical-continuity2.pdf.
[1b] b) a plurality of addressable sensors, disposed along the body and interconnected to a common connector wire; and	CyrusOne's modular sensor assemblies comprise a plurality of addressable sensors, disposed along the body and interconnected to a common connector wire. CyrusOne uses Liebert CRAC units with Liebert sensors. Liebert modular sensors are disposed along the body and interconnected to a common connector wire (string) and are addressable.

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SENSOR-STRING COMPATIBLE

You can attach the sensors in a string, and the string can be a combination of integrated and modular sensors. (Integrated sensors are one or more probes integrated on a single cable.)

A string may include up to 10 probes and be a maximum of 65.6 ft (20 m).

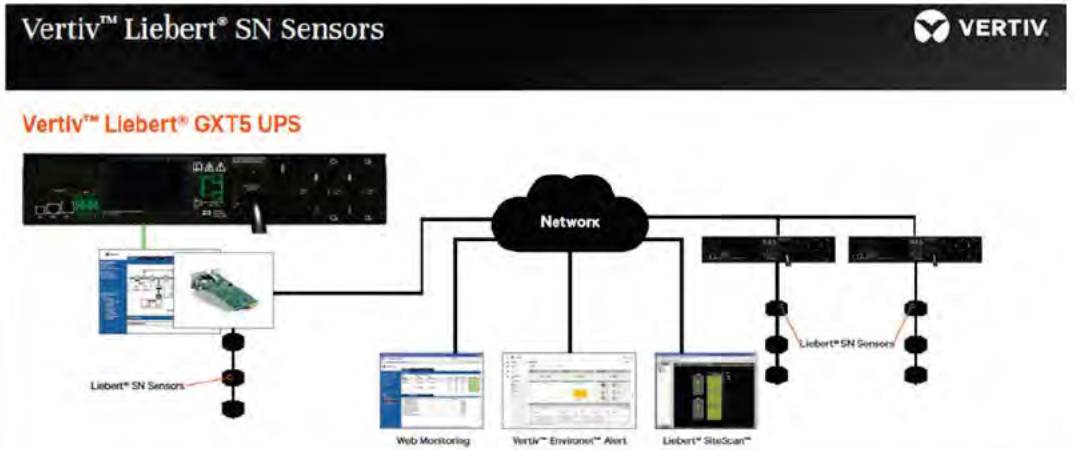
The number of probes that may be used with Liebert monitoring products varies. Refer to the product's user guide for details.

PREPARING FOR INSTALLATION

1. **Record the address of each sensor.**
   During configuration, the web user interface displays the addresses of all connected sensors.

   Before mounting or connecting, locate the sensor address on the sensor housing (see the picture on the following page) and record it.



Claim 1	Exemplary Evidence of Infringement by CyrusOne
	https://www.vertiv.com/49782f/globalassets/shared/liebert-sn-modular-sensors-quick-start-guide_00.pdf.
[1c] c) a connector wire lead, configured to interconnect the connector wire to a central system configured to receive and interpret data from the plurality of sensors relating to conditions associated with the computer rack.	CyrusOne's modular sensor assemblies comprise a connector wire lead, configured to interconnect the connector wire to a central system configured to receive and interpret data from the plurality of sensors relating to conditions associated with the computer rack. CyrusOne uses Liebert CRAC units with Liebert sensors. Liebert modular sensors string at each computer rack is interconnected to a central system (network) to receive and interpret the sensors from multiple computer racks. The networked sensor system is configured with thresholds for alarm and warning triggers.  https://www.vertiv.com/4a84b9/globalassets/shared/liebert-sn-sensors-monitoring-for-business-critical-continuity2.pdf.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	CONFIGURE THE SENSOR Using the sensor address recorded before installation, use the web user interface of your Liebert product to acknowledge the senor connection and configure parameters including labeling the sensor and setting thresholds for alarm/warning triggers. https://www.vertiv.com/49782f/globalassets/shared/liebert-sn-modular-sensors-quick-start-guide_00.pdf.

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EXHIBIT G

REICHMAN JORGENSEN
LEHMAN & FELDBERG LLP

Matthew Berkowitz
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Redwood Shores, CA 94065
Direct Dial: (650) 623-1445
mberkowitz@reichmanjorgensen.com

March 29, 2024

Robert M. Jackson
Executive Vice President, General Counsel and Secretary
CyrusOne
2850 N Harwood St., Suite 2200
Dallas, Texas 75201

Re: Notice of Infringement of Valtrus Innovations Ltd.'s Patents

Dear Mr. Jackson:

My law firm represents Valtrus Innovations Limited ("Valtrus") in various patent matters, including several ongoing patent litigations.

Valtrus is the owner of an extensive portfolio of patents originating from Hewlett Packard Enterprise Company (and/or various related or predecessor companies). Valtrus' portfolio includes nearly 2,000 patents that cover a wide range of products and technologies relating to data centers, cloud computing, server technology, communication devices, and many more. Included in the portfolio are over ninety patents directly related to important technologies implemented in data centers, such as cooling systems and solutions. A representative list of data center-related patents is attached to this letter as Exhibit A. Further details regarding Valtrus may be found on its website at www.valtrusinnovations.ie.

Valtrus has identified numerous data center technologies and systems that infringe one or more patents owned by Valtrus. To this end, Valtrus has initiated patent litigation against Digital Realty Trust and Evoque in the United States District Court for the Eastern District of Texas. The case numbers are 2-24-cv-00139 and 2-24-cv-00142; each involves six patents relating to various data center technologies.

After thorough investigation, Valtrus has identified the following patents practiced by CyrusOne and for which CyrusOne may require a license and/or release:

- U.S. Patent No. 6,862,179 entitled Partition for Varying the Supply of Cooling Fluid
- U.S. Patent No. 6,718,277 entitled Atmospheric Control within a Building
- U.S. Patent No. 6,854,287 entitled Cooling System
- U.S. Patent No. 7,339,490 entitled Modular Sensor Assembly
- U.S. Patent No. 7,031,870 entitled Data Center Evaluation Using an Air Re-Circulation Index
- U.S. Patent No. 9,310,855 entitled Flexible Data Center and Methods for Deployment
- U.S. Patent No. 7,939,967 entitled Multiple Power Supply Control

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This list is preliminary, and our analysis is ongoing. We expect that we will identify additional patents that are practiced by CyrusOne in due course. From this list we have also prepared several exemplary claim charts using publicly available sources, attached as Exhibit B, which provide more detail about how we believe that CyrusOne infringes the identified patents.

Valtrus hereby offers CyrusOne the opportunity to license any or all of the Valtrus patents. If CyrusOne is interested in concluding such a license, Valtrus would like to arrange a meeting (either in person or virtual) during the week of April 22, 2024, with appropriate representatives of both companies to discuss this matter in greater detail. At that time, we would hope to reach an agreement with you on an overall process and timeline for concluding such a license. We would also be prepared to explain in greater detail the claim charts we are providing and to hear any response you may have regarding the same.

Valtrus fully understands that with respect to certain technologies, Valtrus has incomplete knowledge regarding the products, systems and solutions implemented by CyrusOne in its data centers, as CyrusOne data centers are secure facilities that are not open to the public. Thus, we suggest, as part of the overall process, the parties enter into a non-disclosure agreement that would provide Valtrus and/or its representatives access to CyrusOne confidential documentation (including data center access) so Valtrus can, in good faith, confirm the scope and extent of CyrusOne's infringement.

Please let us know as soon as possible, but no later than April 15, whether CyrusOne is agreeable to the aforementioned meeting. If we do not hear from you by that time, we will assume that CyrusOne is not interested in a license from Valtrus. Valtrus of course reserves all rights.

I look forward to hearing from you.

Sincerely,



Matthew Berkowitz

Enclosure

Copy to:

Angela Quinlan – Valtrus Innovations, Ltd.
Paul Riley – Patent Platform Services (licensing representative of Valtrus Innovations, Ltd.)

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Exhibit A Page **1**

Patent	Category	Title
US6525936B2	Cooling	Air jet cooling arrangement for electronic systems
US6609208B1	Power Management	Energy-based sampling for performance monitoring
US6644481B2	Rack	Apparatus and method for rackmounting a chassis
US6650537B2	Power Management	Low profile DC distribution module for a power supply unit
US6657867B2	Rack	Hinged door for access to add-in cards
US6661651B1	Rack	Mounting of data storage devices with compliant storage module covers
US6666340B2	Rack	Universal rack rail
US6702124B2	Rack	Flat spring clip for tool-less slide installation
US6718277B2	Cooling	Atmospheric control within a building
US6829142B2	Cooling	Cell thermal connector
US6832168B2	Power Management	Method and system for verifying network device power cabling configuration
US6832927B2	Rack	Low profile PCI hot plug actuator assembly
US6834811B1	Cooling	Market-based temperature control system and method
US6848114B2	Rack	Bulk access system for a data storage system
US6850866B2	Management	Managing performance metrics describing a relationship between a provider and a client
US6854284B2	Cooling	Cooling of data centers
US6854287B2	Cooling	Cooling system
US6858792B2	Rack	Tool-less coupling assembly
US6862179B2	Cooling	Partition for varying the supply of cooling fluid
US6862185B2	Cooling	Systems and methods that use at least one component to remove the heat generated by at least one other component
US6862186B2	Heat sink	Stack up assembly
US6868682B2	Cooling	Agent based control method and system for energy management
US6868683B2	Cooling	Cooling of data centers
US6873530B2	Heat sink	Stack up assembly
US6876549B2	Cooling	Method and apparatus for individually cooling components of electronic systems
US6879487B2	Cooling	Fan-securing device for use with a heat transfer device
US6886353B2	Cooling	Cooling system

Patent	Category	Title
US6900987B2	Heat sink	Stack up assembly
US6901303B2	Cooling	Method and apparatus for controlling fans and power supplies to provide accelerated run-in testing
US6904968B2	Cooling	Method and apparatus for individually cooling components of electronic systems
US6922340B2	Heat sink	Stack up assembly
US6928580B2	Management	Distributed data center system protocol for continuity of service in the event of disaster failures
US6935419B2	Heat sink	Heat sink apparatus with air duct
US6938433B2	Cooling	Cooling system with evaporators distributed in series
US6945058B2	Cooling	Cooling of data centers
US6947286B2	Heat sink	Stack up assembly
US6963970B2	Management	System and method for executing a fast reset of a computer system
US6982877B2	Heat sink	Heat sink having compliant interface to span multiple components
US7013968B2	Cooling	Method and apparatus for individually cooling components of electronic systems
US7020145B1	Management	Network topology manager
US7027309B2	Rack	Engaging/disengaging mechanism
US7031870B2	Cooling	Data center evaluation using an air re-circulation index
US7054156B2	Cooling	Fan rotor systems having collapsible fan blades
US7075788B2	Cooling	Computer cooling system and method
US7079390B2	Heat sink	System and method for heat dissipation and air flow redirection in a chassis
US7082032B1	Heat sink	Heat dissipation device with tilted fins
US7086459B2	Cooling	Method and apparatus for individually cooling components of electronic systems
US7145775B2	Heat sink	Chassis conducted cooling thermal dissipation apparatus for servers
US7152174B2	Power Management	Method and apparatus for operating a server system including determining the power supplied by one of a plurality of power supplies by measuring voltage on a load share signal line

Patent	Category	Title
US7222246B2	Power Management	Method for determining number of dynamically temperature-adjusted power supply units needed to supply power according to measure operating temperature of power supply units
US7251547B2	Cooling	Correlation of vent tile settings and rack temperatures
US7251588B2	Management	System for metric introspection in monitoring sources
US7269753B2	Power Management	Mapping power system components
US7336490B2	Heat sink	Multi-chip module with power system
US7337018B2	Cooling	Heat sink fan management based on performance requirements
US7339490B2	Rack	Modular sensor assembly
US7360295B2	Rack	System and method for securely positioning apparatus within a housing
US7447026B2	Cooling	System for hot swapping heat exchangers
US7499281B2	Heat sink	Multi-chip module with power system
US7499286B2	Rack	Mounting adapter for electronic modules
US7512825B2	Power Management	Responding to DC power degradation
US7514816B2	Power Management	Output current threshold adjustment for a power supply
US7546475B2	Power Management	Power-aware adaptation in a data center
US7548421B2	Cooling	Impingement cooling of components in an electronic system
US7555751B1	Management	Method and system for performing a live system upgrade
US7765299B2	Rack	Dynamic adaptive server provisioning for blade architectures
US7822857B2	Management	Methods and systems for sharing remote access
US7895455B2	Power Management	Dynamic converter control for efficient operation
US7939967B2	Power Management	Multiple power supply control
US7995339B2	Cooling	Control of vent tiles correlated with a rack
US8214786B2	Rack	Scalable, component-accessible, and highly interconnected three-dimensional component arrangement within a system
US8353489B2	Rack	Mounting kit
US8355251B2	Rack	Remote exhaust for rack systems

Patent	**Category**	**Title**
US8355828B2	Power Management	Determining optimal settings for resource actuators
US8379538B2	Management	Model-driven monitoring architecture
US8395896B2	Cooling	Redundant cooling systems and methods
US8526325B2	Management	Detecting and identifying connectivity in a network
US8539059B2	Cooling	Managing cooling devices and computing nodes in an infrastructure
US8661283B2	Power Management	Power distribution unit-device correlation
US8676931B1	Management	Methods for managing manual changes to network infrastructures through automated systems
US8677365B2	Cooling	Performing zone-based workload scheduling according to environmental conditions
US8694991B2	Management	Server virtualized using virtualization platform
US8712597B2	Cooling	Method of optimizing air mover performance characteristics to minimize temperature variations in a computing system enclosure
US8782450B2	Power Management	Power capping system and method
US8798964B2	Rack	Methods and apparatus for designing the racking and wiring configurations for pieces of hardware
US9098276B2	Power Management	Redundant power supply systems and methods
US9179580B2	Cooling	Data center cooler with chiller and cooling tower
US9240931B2	Management	Information technology service management
US9310855B2	Cooling	Flexible data center and methods for deployment
US9354678B2	Cooling	Enclosure airflow controller
US9395786B2	Power Management	Cross-layer power management in a multi-layer system

U.S. Patent No. 6,862,179 – Infringement Claim Chart

Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1pre] A method of cooling a plurality of racks in a data center, said method comprising:	CyrusOne's data centers use a method of cooling a plurality of racks in a data center. For example, CyrusOne uses Vertiv (Liebert) downflow chilled water CRAC units in the colocation data center. Liebert CRAC units are controlled by Liebert's iCOM Intelligent Communication and Monitoring system.  https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

Cooling

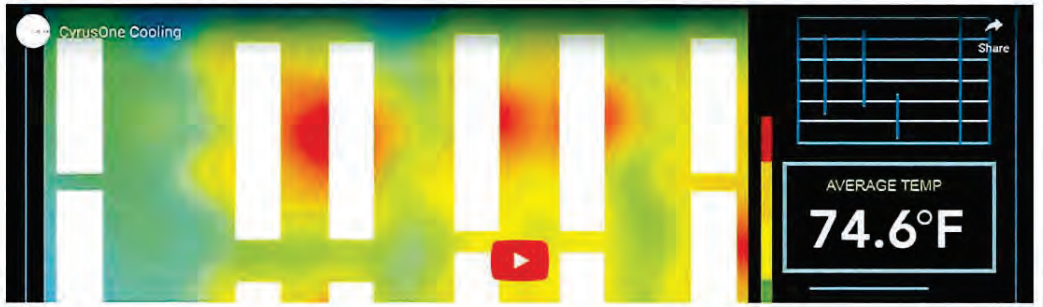
- N+1 Cooling
- Redundant DX and Glycol Chillers
- Redundant raised floor CRAC units
- 12in Raised floor

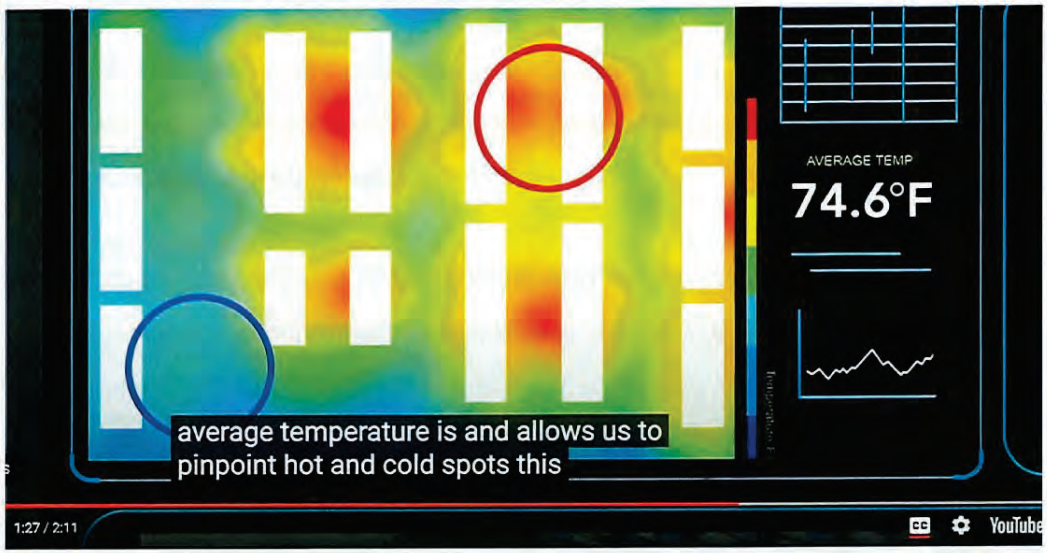
https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.

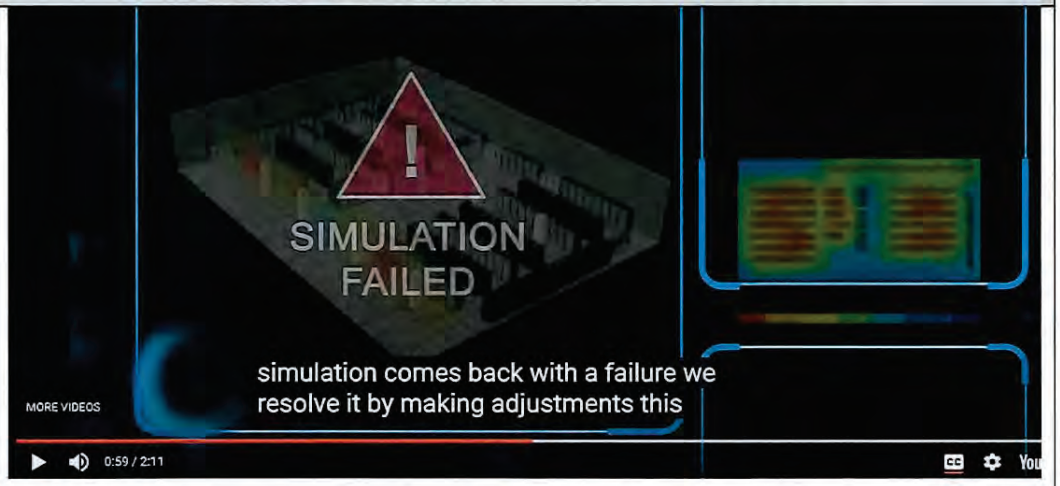


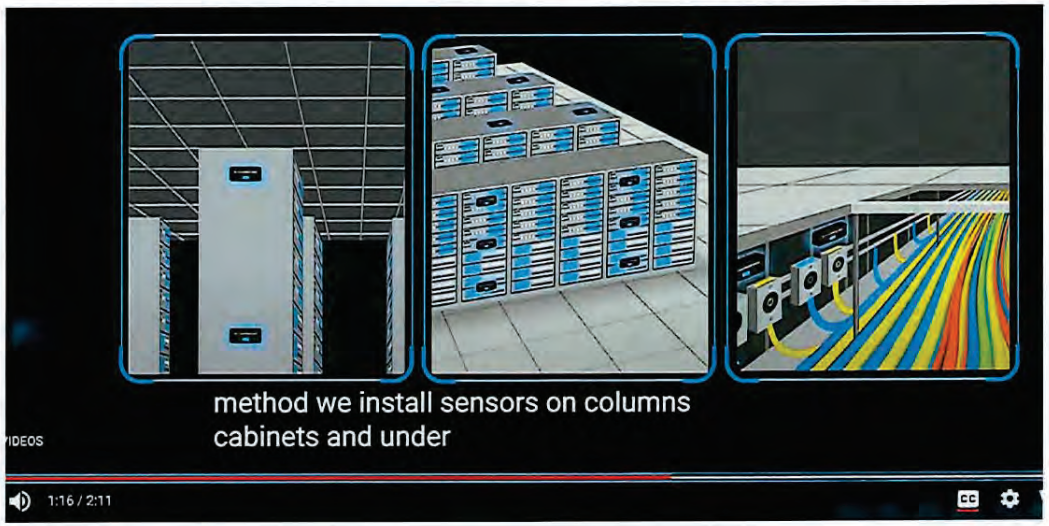
https://www.vertiv.com/49d637/globalassets/shared/liebert-icom-thermal-system-controls-brochure.pdf ("iCOM Brochure").

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	At the cooling unit level, the Liebert iCOM unit control provides the highest protection available and optimal performance. • Monitors 380 unit and component points to eliminate single points of failure • Self-healing features avoid passing unsafe operating thresholds • Highly intuitive, full-color, touch screen simplifies operations to save time and reduce human error • Multiple, automated unit protection routines, including lead/lag, cascade, rapid restart, refrigerant protection and valve calibration  **At the supervisory level,** the Liebert iCOM-S system control offers a revolutionary way to harmonize and optimize thermal system performance to optimize capacity across the data center, gain quick access to actionable data, and automate system diagnostics and trending. • Advanced monitoring and at-a-glance reporting on performance metrics and trends for efficiency, capacity and adverse events • Up to 50% system efficiency gains • 30% lower deployment costs • Teamwork modes that prevent conflict between units and allow them to adapt to changes in facility and IT demand to improve efficiency and availability and reduce system wear and tear – saving more than $10,000 per unit per year in energy costs • Simple and easy to deploy — auto-configuration to detect and configure up to 4,800 sensors, eliminating the need for custom integration to building management systems and cutting sensor deployment times in half Liebert iCOM unit control and Liebert iCOM-S system control are available for new Vertiv™ data center cooling units or as retrofits.  iCOM Brochure at p. 3. CyrusOne also uses CyrusOne cooling to continuously optimize air flow in its colocation data centers.

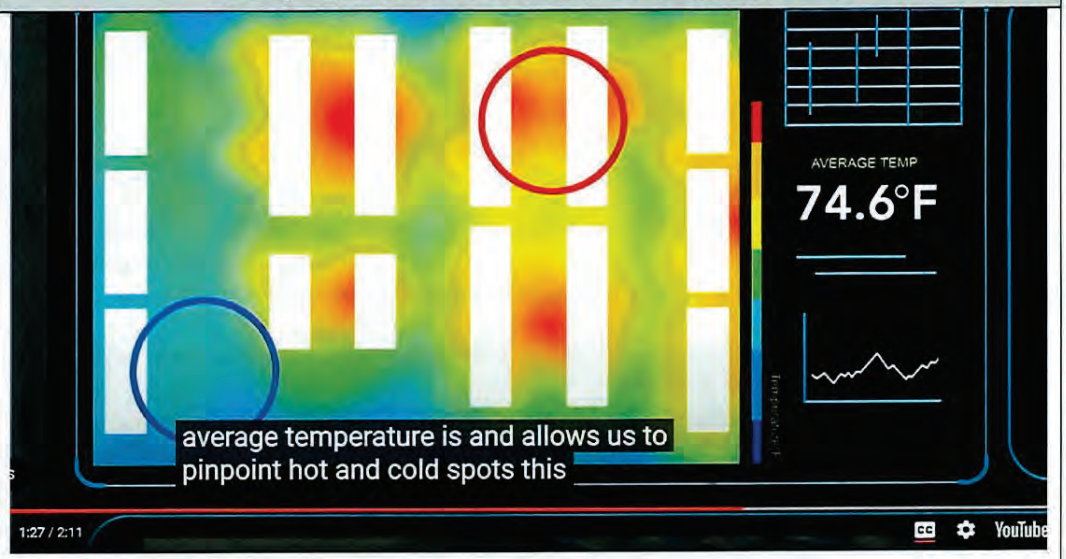
Claim 1	Exemplary Evidence of Infringement by CyrusOne
	CyrusOne's data center cooling systems are some of the most advanced in the world employing proactive and reactive methods to keep customer's data halls running at the most optimal temperatures.  https://www.cyrusone.com/data-center-solutions/colocation
[1a] activating a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks;	CyrusOne activates a cooling device and opening a controllable partition configured to vary a supply of cooling fluid within a zone of said data center, said zone including at least one associated rack of said plurality of racks. For example, Liebert's iCOM Intelligent Communication and Monitoring fluid economizer system activates the flow of chilled water/glycol, and varies cooling capacity by adjusting a motorized ball valve (controllable partition). **7.1.4 Temperature Control with a Fluid Economizer** When an economizer is installed, the cooling requirement (determined by the temperature proportional band) is addressed first by the economizer's secondary cooling, if the economizer cooling capacity is insufficient, the compressor(s) begin cooling to bring the room air temperature down to the temperature setpoint. The fluid economizer employs a motorized ball valve that controls the flow of chilled water/glycol to provide a cooling capacity from 0% to 100%. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 110.

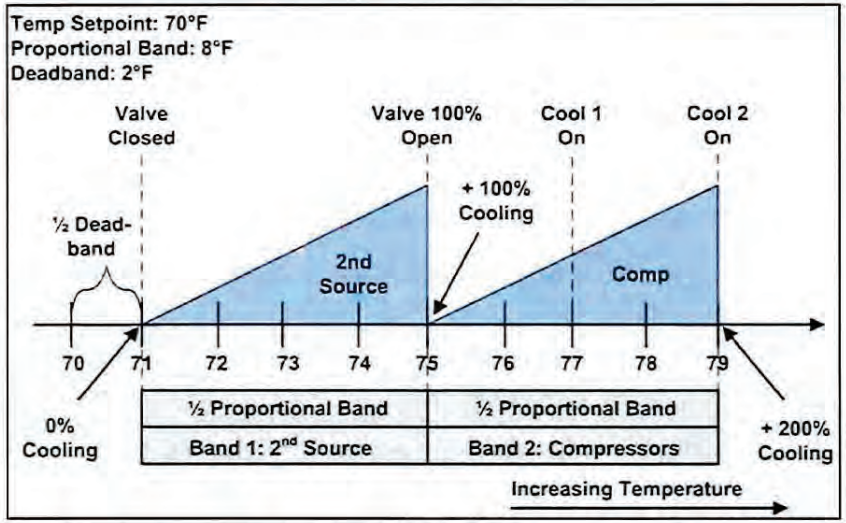
Claim 1	Exemplary Evidence of Infringement by CyrusOne
	CyrusOne also uses CyrusOne Cooling which is a closed-loop system that reacts to real-time data, automatically identifies and eliminates hot spots and helps diagnose potential facility risks by making adjustments.  https://www.cyrusone.com/data-center-solutions/colocation , at 1:27;

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.cyrusone.com/data-center-solutions/colocation , at 0:59;
[1b] sensing the temperature of said at least one associated rack;	CyrusOne senses the temperature of said at least one associated rack. For example, CyrusOne uses Liebert cooling units and the Liebert cooling unit control system senses temperatures. **13.2 Installing Wired Remote Sensors** Up to 10 remote sensor modules, installed in the monitored racks and connected to the cooling unit, provide control and reference input to iCOM and building-management systems. Using remote, rack sensors combats cooling problems related to recirculation air, uneven rack loading, and air distribution. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 180. CyrusOne also uses CyrusOne cooling which installs temperature sensors to determine exactly where the heat load is within the data center. Data is wirelessly transmitted to

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	network gateways, aggregated, and sent to a purpose-built appliance where it is analyzed by control software. Control commands are then delivered to the cooling equipment.  https://www.youtube.com/watch?v=yFMS-88wXn8, at 1:16.
[1c] determining whether said sensed temperature is within a predetermined temperature range; and	CyrusOne determines whether said sensed temperature is within a predetermined temperature range. For example, CyrusOne uses the Liebert iCOM system which is able to identify if the temperature is at the setpoint value, and change the response to the varied flow field based on length of time temperature has deviated, and amount of deviation from setpoint.

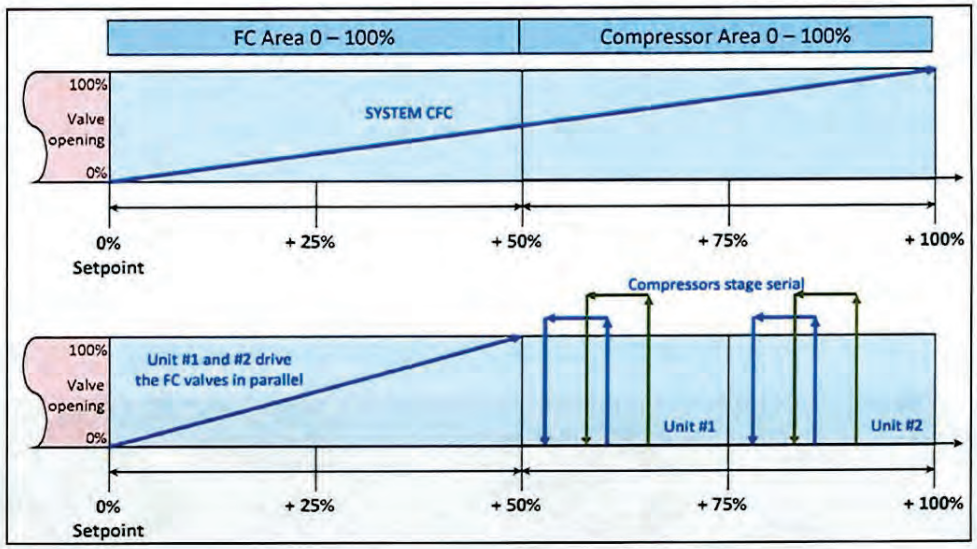
Claim 1	Exemplary Evidence of Infringement by CyrusOne
	Temperature Integration Time Adjusts amount of cooling/heating based on the length of time the temperature has deviated from the setpoint. The time selected is the amount of time it will take cooling capacity to reach 100%. For example, if three minutes is selected, cooling capacity will increase to 100% in three minutes. NOTE: Three to five minutes of integration time is adequate for most applications. See Considerations when Using PI Temperature Control on page 28 . NOTE: Only used when Temperature Control Type is PI. **Temperature Proportional Band** Adjusts the activation point of cooling/heating components based on deviation from setpoint by placing half of the selected value on each side of the temperature control setpoint. A smaller number causes faster reaction to temperature changes. NOTE: Setting this too low causes short cycling of compressors. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 25. CyrusOne also uses CyrusOne Cooling to determine whether the sensed temperature is within a predetermined temperature range, for example, by using hot and cold spots.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.cyrusone.com/data-center-solutions/colocation , at 1:27;
[1d] manipulating said controllable partition to vary said supply of said cooling fluid to said zone in response to said sensed temperature being outside said predetermined temperature range.	CyrusOne manipulates said controllable partition to vary said supply of said cooling fluid to said zone in response to said sensed temperature being outside said predetermined temperature range. CyrusOne uses Liebert's iCOM system to manipulate the motorized ball valve (controllable partition) from 0% to 100% flow of chilled water/glycol. **7.1.4 Temperature Control with a Fluid Economizer** When an economizer is installed, the cooling requirement (determined by the temperature proportional band) is addressed first by the economizer's secondary cooling, if the economizer cooling capacity is insufficient, the compressor(s) begin cooling to bring the room air temperature down to the temperature setpoint. The fluid economizer employs a motorized ball valve that controls the flow of chilled water/glycol to provide a cooling capacity from 0% to 100%.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 110. Figure 3.17 Second Cooling Source and Two-Step Compressorized Cooling  https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 69, Fig. 3.17.

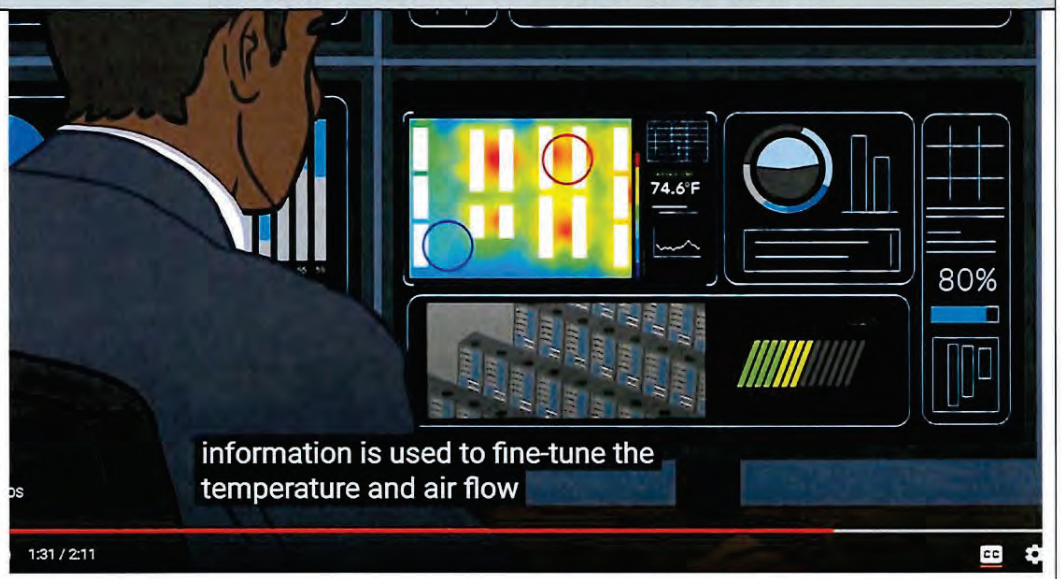
Claim 1	Exemplary Evidence of Infringement by CyrusOne

Figure 3.18 Freecooling and Compressorized Operation



https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf, p. 70, Fig. 3.18.

CyrusOne also uses CyrusOne Cooling Optimize to adjust cooling output by fine-tuning the air flow.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.cyrusone.com/data-center-solutions/colocation , at 1:31;

U.S. Patent No. 6,718,277 – Infringement Claim Chart

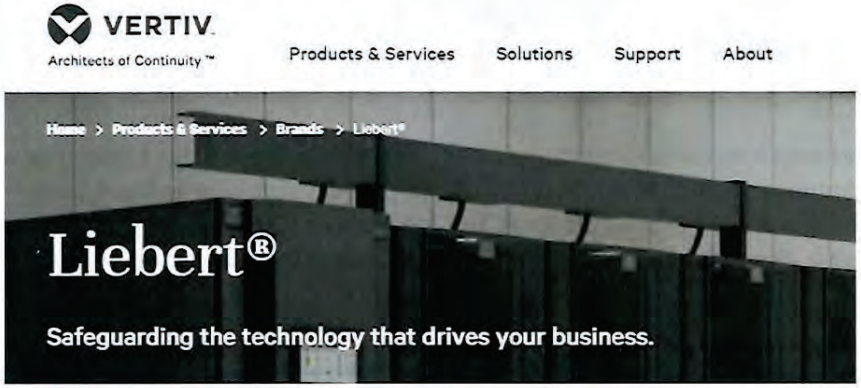
Claim 1	Exemplary Evidence of Infringement by CyrusOne
[1pre] A method of controlling atmospheric conditions within a building, said method comprising the steps of:	CyrusOne's data centers use a method of controlling atmospheric conditions within a building. CyrusOne uses Vertiv and Liebert cooling in its U.S. data centers to control atmospheric conditions. Liebert's cooling units are controlled, for example, by Liebert's iCOM and/or iCOM-S Intelligent Communication and Monitoring System, which uses a method for evaluating one or more components in a data center.  https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 1.

Claim 1	Exemplary Evidence of Infringement by CyrusOne

Cooling

- N+1 Cooling
- Redundant DX and Glycol Chillers
- Redundant raised floor CRAC units
- 12in Raised floor

https://documents.cyrusone.com/wp-content/uploads/2023/06/2022-CIN97_Cincinnati.pdf, p. 2.



https://www.vertiv.com/en-us/products/brands/liebert/

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.vertiv.com/49d637/globalassets/shared/liebert-icom-thermal-system-controls-brochure.pdf ("iCOM Brochure").

Claim 1	Exemplary Evidence of Infringement by CyrusOne

At the cooling unit level, the Liebert iCOM unit control provides the highest protection available and optimal performance.

- Monitors 380 unit and component points to eliminate single points of failure
- Self-healing features avoid passing unsafe operating thresholds
- Highly intuitive, full-color, touch screen simplifies operations to save time and reduce human error
- Multiple, automated unit protection routines, including lead/lag, cascade, rapid restart, refrigerant protection and valve calibration



At the supervisory level, the Liebert iCOM-S system control offers a revolutionary way to harmonize and optimize thermal system performance to optimize capacity across the data center, gain quick access to actionable data, and automate system diagnostics and trending.

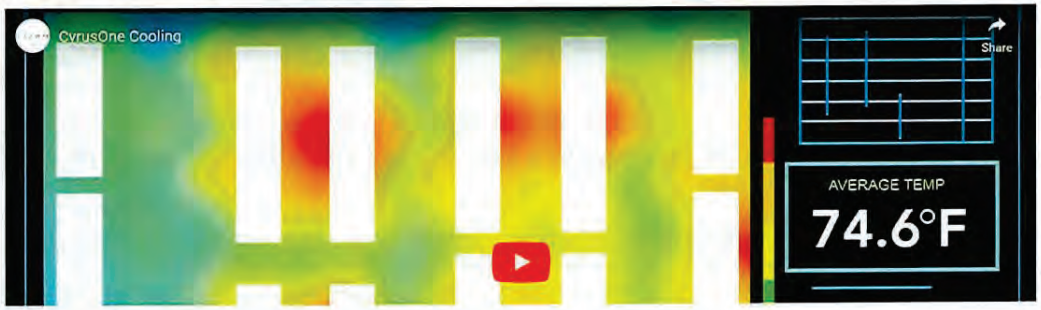
- Advanced monitoring and at-a-glance reporting on performance metrics and trends for efficiency, capacity and adverse events
- Up to 50% system efficiency gains
- 30% lower deployment costs
- Teamwork modes that prevent conflict between units and allow them to adapt to changes in facility and IT demand to improve efficiency and availability and reduce system wear and tear – saving more than $10,000 per unit per year in energy costs
- Simple and easy to deploy — auto-configuration to detect and configure up to 4,800 sensors, eliminating the need for custom integration to building management systems and cutting sensor deployment times in half

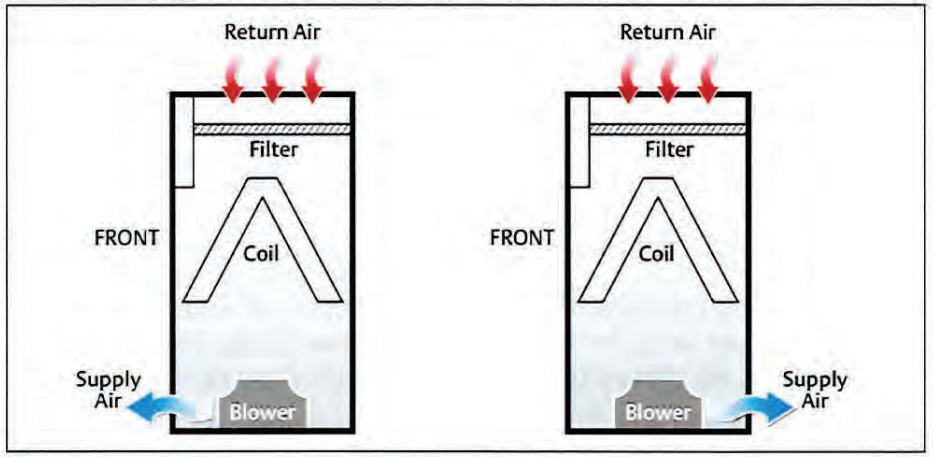
Liebert iCOM unit control and Liebert iCOM-S system control are available for new Vertiv™ data center cooling units or as retrofits.



iCOM Brochure at p. 3.

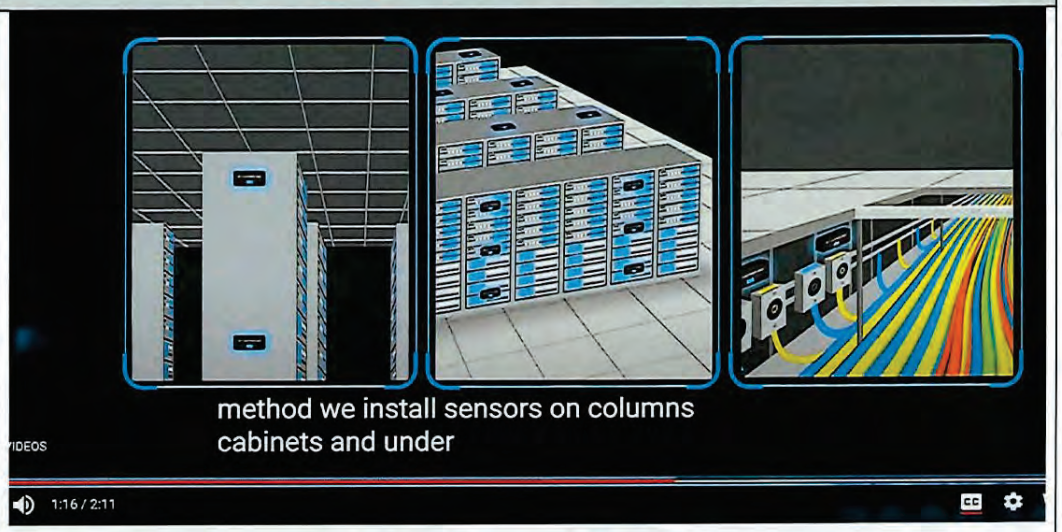
CyrusOne also uses CyrusOne cooling software to measure, monitor, and manage atmospheric conditions in its data centers.

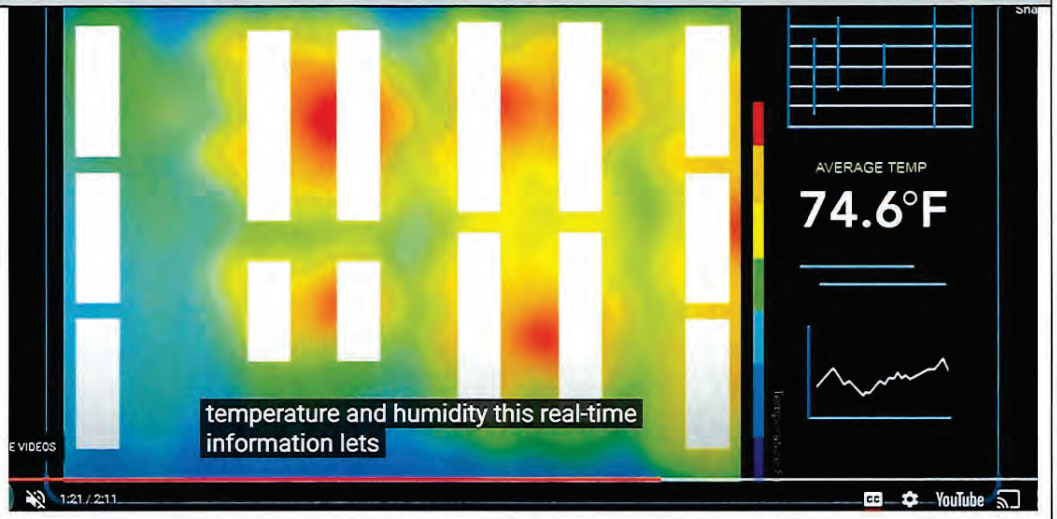
Claim 1	Exemplary Evidence of Infringement by CyrusOne
	CyrusOne's data center cooling systems are some of the most advanced in the world employing proactive and reactive methods to keep customer's data halls running at the most optimal temperatures.  https://www.cyrusone.com/data-center-solutions/colocation
[1a] supplying a conditioned fluid inside said building;	CyrusOne supplies a conditioned fluid inside said building. For example, CyrusOne uses CRAC units inside its data centers to supply conditioned fluid. CyrusOne uses Liebert to control atmospheric conditions in the data center with its CRAC units. CyrusOne supplies refrigerant (conditioned fluid) through the coil of its Liebert CRAC units. The Liebert CRAC unit receives the "return air" from the room and delivers cool conditioned "supply air" to the room (supplying conditioned fluid), by transferring heat from the air to the cooling fluid within the coil.

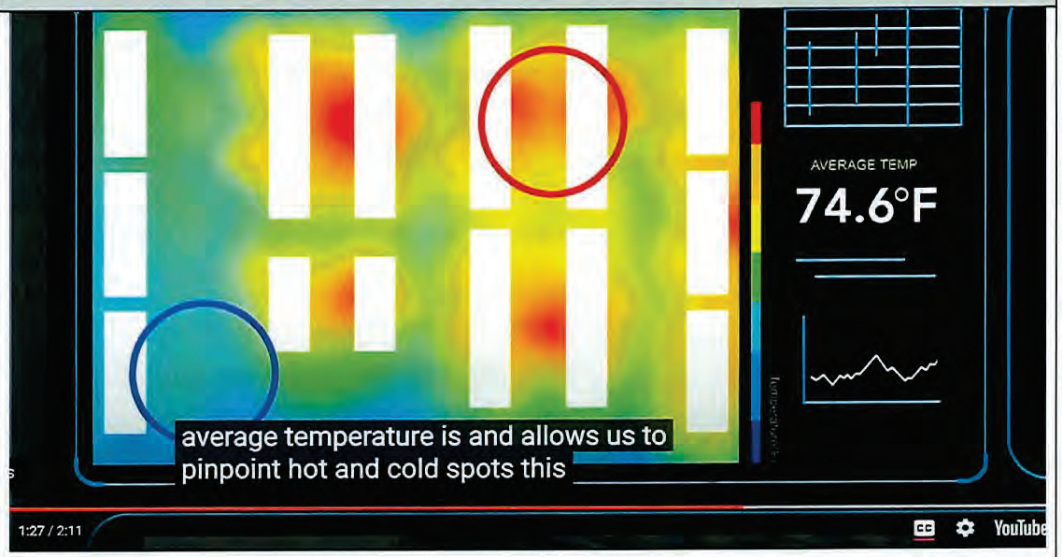
Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.vertiv.com/4afe7d/globalassets/products/thermal-management/room-cooling/liebert-dse-80-165kw-23-43-tons-downflow-system-design-manual.pdf, at p. 6. Regardless of which type of CRAC units or which method of controlling atmospheric conditions are used (Liebert, CyrusOne, or others), CyrusOne supplies a conditioned fluid inside each of its data centers.
[1b] sensing at least one atmospheric parameter in a plurality of locations inside said building;	CyrusOne senses at least one atmospheric parameter in a plurality of locations inside said building. For example, CyrusOne uses Liebert iCOM. Liebert iCOM senses temperatures and humidity at locations throughout the data center.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	User Temperature Setpoint Options **2nd Temperature Setpoint** Alternate setpoint activated by customer input (remote alarm device). When customer input connection is 2nd Setpoint, this value becomes the active temperature setpoint. **BMS Backup Temp Setpoint** Selects a temperature setpoint that activates in the event of a BMS timeout. The BMS timer must be configured for this setpoint to activate. See Setting BMS Backup Setpoints on page 117. **Optimized Aisle Enabled** Read-only. Indicates that iCOM™ is configured for optimized-aisle operation. See Teamwork Mode 3—Optimized Aisle Operation on page 102. **Temperature Control Sensor** Selects sensor that controls cooling. Values are: • Supply Sensor: Temperature control is based on maintaining the temperature of the discharge air from the cooling unit. See Supply Sensors on page 158. • Remote Sensor: Temperature control is based on the temperature reading(s) from wired remote sensor(s). See Wired Remote Sensors on page 156. • Return Sensor: Temperature control is based on maintaining the temperature of the air returning to the cooling unit.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	User Humidity Setpoint Options **Dew Point Setpoint** Desired dew point (based on actual return air temperature and humidity) by adding moisture to or removing moisture from the air. **Humidity Control Sensor** Selects sensor used when calculating relative humidity. **Humidity Control Type** Control when staging humidification operations. Valid values: • Relative: Percent of humidification/dehumidification is determined by the difference between the humidity-sensor reading and the humidity setpoint. • Compensated: Percent of humidification/dehumidification is determined by considering the actual deviation from the temperature setpoint and adjusts the humidity setpoint accordingly. The recalculated humidity setpoint displays on the screen. • Predictive: Percent of humidification/dehumidification is determined by considering the actual deviation from the temperature setpoint and adjusts the humidity sensor reading accordingly. The adjusted humidity sensor reading displays on the screen. • Dew point: Percent of humidification/dehumidification is determined by the difference between the dew point calculated from the humidity sensor reading and the dew point setpoint. https://www.vertiv.com/49b8b2/globalassets/shared/liebert-icom-user-manual_sl-31075.pdf ("iCOM Manual") at p. 15-16. CyrusOne also uses CyrusOne Cooling to sense temperatures based on real sensor readings at various locations inside the data center.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.youtube.com/watch?v=yFMS-88wXn8, at 1:16.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.youtube.com/watch?v=yFMS-88wXn8, at 1:21.

Claim 1	Exemplary Evidence of Infringement by CyrusOne
	 https://www.cyrusone.com/data-center-solutions/colocation , at 1:27;
[1c] generating an empirical atmospheric map from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical atmospheric map;	CyrusOne an empirical atmospheric map from the results of said sensing step using software for processing input from said sensing step and for producing output in the form of said empirical atmospheric map. For example, CyrusOne uses Liebert iCOM. Liebert iCOM generates an empirical atmospheric map from the results of sensing temperature at individual racks. Liebert iCOM uses software for processing temperature inputs from the sensing step and produces output in the form of a data center temperature map.